# BUILDING CONSTRUCTION

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THE CHRYSLER BUILDING, NEW YORK CITY
Height 808 ft. or 68 Stories.

# BUILDING CONSTRUCTION

## TYPES OF CONSTRUCTION, MATERIALS, AND COST ESTIMATING


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# BUILDING CONSTRUCTION

## CHAPTER I

## INTRODUCTION

### ARTICLE 1. THE BUILDING INDUSTRY

Before considering the various types of buildings and the elements of which they are composed, a general survey of the building industry will be of value.

The annual expenditure in this country for buildings during recent years has been over seven billion dollars or about ten per cent of our total annual income. The new floor space added each year exceeds one billion square feet. This is twenty-three thousand acres or thirty-seven square miles.

There has been a pronounced increase in building since the World War. The volume of building in 1925 was about two and one-quarter times that of 1913 but due to the increased wages and material prices the expenditure in 1925 was nearly five times that of 1913. From 1925 to 1928 inclusive there were no marked changes in the annual volume of construction or the expenditures.



Some authorities are of the opinion that the volume of construction during the years 1925 to 1928 represents the normal requirements of the country to take care of the two-million annual increase in population, the replacement of old buildings, the industrial expansion, and the very large annual fire loss and that it is probable that a gradual increase in the annual construction volume may be expected for some time to come, with fluctuations from year to year.

The cost of building was subject to only minor fluctuations for the six-year period from 1923 to 1928 inclusive. During this period the cost was a little more than twice the pre-war cost. See Fig. 168.

The distribution of the annual expenditure between various classes of construction varies from year to year but the average requirements are about as follows:[1]

[1] Compiled from Commerce Year Book for 1928. U. S. Department of Commerce, Vol. I, p. 323.

| | Per cent |
|---|---|
| Residential (dwellings, apartments, hotels) | 42 |
| Public works and utilities | 17 |
| Commercial | 15 |
| Industrial | 9 |
| Educational | 7 |
| Social and recreational | 4 |
| Religious and memorial | 2.5 |
| Hospitals and institutions | 2.5 |
| Public buildings | 1.0 |
| | 100.0 |

These figures indicate that 83 per cent of the expenditure on construction work is for buildings and 17 per cent for public works and utilities.

The design and construction of buildings require the services of architects, engineers, contractors, skilled mechanics, laborers, and many other classes of workers such as draftsmen and clerks. At the time of the 1920 census there were about 18,000 architects in this country, and 90,000 builders and building contractors. Estimates for 1928 have placed the number of builders and building contractors at 270,000 in 1928 but this figure seems excessive.[1] Contractors are divided into general contractors whose contracts include all or at least a large part of the work on a building and subcontractors who devote their attentions to only one branch of the work. Reports of the F. W. Dodge Corporation show that 7,600 general contractors handled all of the general contracts over $25,000 awarded during the last few years in 37 states including 90 per cent of the country's population. About 60 per cent of the total building operations are by general contractors.[2]

At the time of the 1920 census, the number of skilled workers engaged in building construction was about 1,800,000 and the number of laborers about 600,000 making a total of about 2,400,000. Between 1920 and 1928 there was an increase of 20 per cent in the population and 75 per cent or more in the physical volume of building construction, but no dependable figures are available for the increase in the number of building workers. However, the increase in union labor as indicated by the membership in the American Federation of Labor will give some indication of the trend, since most of the skilled laborers in cities belong to the trades unions. The membership in the trades unions requiring skilled workers was about 760,000 in 1920 and 850,000 in 1928, representing an

[1] Engineering News-Record, November 29, 1928, p. 826.

[2] Thomas S. Holden, Vice President, F. W. Dodge Corporation, American Contractor, January 7, 1928.


*Voorhees, Gmelin, & Walker, Architects*

New York Telephone Building

increase of 12 per cent.[1] The Department of Commerce estimated[2] nearly five million skilled workers in the building trades in 1928, but this figure seems excessive. About 40 per cent of the cost of a building is for labor performed at the building site.

Wages for skilled labor vary from 60 cents to $1.75 per hour but with a few exceptions the range is from $1.00 to $1.50. The average for the country is about $1.35. Wages for common labor vary from 25 cents to 90 cents per hour with the exception of hod carriers who in some cases receive as high as $1.25 per hour. The average wage for common labor is about 57 cents per hour.

In spite of the objection to tall buildings on account of their supposed effect on traffic congestion and on living conditions in general, skyscrapers are being constructed at an increasing rate. It has been estimated that under conditions which prevail in the area near the Grand Central Station in New York City the rate of return on a building occupying a ground area of 200 by 400 ft. reaches a maximum at a height of 75 stories.[3] In general, a much lower limit of 20 or 30 stories probably prevails. The highest building in the world for the period from 1914 to 1929 was the Woolworth Building in New York City with 60 stories and a height of 792 ft., but the Chrysler Building now assumes that distinction with a height of 68 stories or 808 ft. and an estimated cost of $14,000,000 for the building not including the land it occupies. The most valuable building in New York City according to assessed valuation is the Equitable Office Building with a valuation of $31,000,000[4] for the building and the land which it occupies. This building provides quarters for 10,000 people. The Merchandise Mart in Chicago has a floor area of over 4,000,000 sq. ft. or 93 acres. This is the largest floor area of any building in this country. The deepest foundations for any building in the country are those for the piers supporting the tower of the Cleveland Union Terminal Building which rest on rock 262 ft. below the curb level. See Fig. 20. One of the longest roof spans is that of the three-hinged arches of the Field House at the University of Minnesota which is 220 ft. See Fig. 97.

### ARTICLE 2. CLASSIFICATION AND GENERAL REQUIREMENTS FOR BUILDINGS

**Building Codes.** — Types of construction, quality of materials, floor loads, allowable stresses, and all other requirements relating to buildings are covered by building codes. Each city has its own building code to

[1] American Labor Year Book, 1928, Rand School of Social Science.

[2] Engineering News-Record, November 29, 1928, p. 826.

[3] W. C. Clark, Economist for S. W. Strauss & Co., Engineering News-Record, Vol. 99, p. 718.

[4] World's Almanac, 1928.

which the buildings of that city must conform. There is great lack of uniformity in these codes even where there is no reason for variation. For identical conditions, the floor loads, the allowable stresses, the wall thickness and many other items vary through a wide range. This results either in a waste of material or a sacrifice of safety and leads to confusion among architects and engineers whose practice is not confined to one city.

Many agencies are at work to improve this situation. The Building Code Committee of the Department of Commerce has published reports on several phases of the problem; The Pacific Coast Building Officials Conference has published a Uniform Building Code; The National Board of Fire Underwriters has published a Recommended Building Code; and the American Society for Testing Materials has published numerous specifications for materials. Frequent reference will be made to these publications.

**Authority for Building Codes.** — The legal principles involved in the enforcement of building code requirements are outlined in the following paragraph quoted from a report of the Building Code Committee of the Department of Commerce:[1]

> Code requirements depend on what is known as the "police power" for enforcement. The police power is that inherent power of government which protects the people against harmful acts of individuals, so far as matters of safety, health, morals, or the like are concerned; and unless a code requirement can be shown to be necessary for such protection, it will not be supported by the courts. The limits of the police power have never been defined lest its flexibility be lost, but, in general, are gradually being extended. It has at times received very broad interpretation, but the usual result when a border-line case is brought into court is to defeat the requirement and to undermine the authority of the building official. Authority to exercise the police power is delegated by the state authorities to cities and a police power regulation enacted by the state legislature will, in general, outweigh a conflicting provision enacted by local authorities.

**Classification According to Construction.** — Building codes commonly classify buildings according to the type of construction and according to use or occupancy. Here the classifications of the Building Code of the National Board of Fire Underwriters will be followed quite closely.

Buildings may be classified according to type of construction as follows:

1. Frame construction.
2. Non-fireproof construction.
   (a) Ordinary construction.
   (b) Mill construction (sometimes called Slow-burning construction).
3. Fireproof construction.

[1] Recommended Practice for Arrangement of Building Codes.

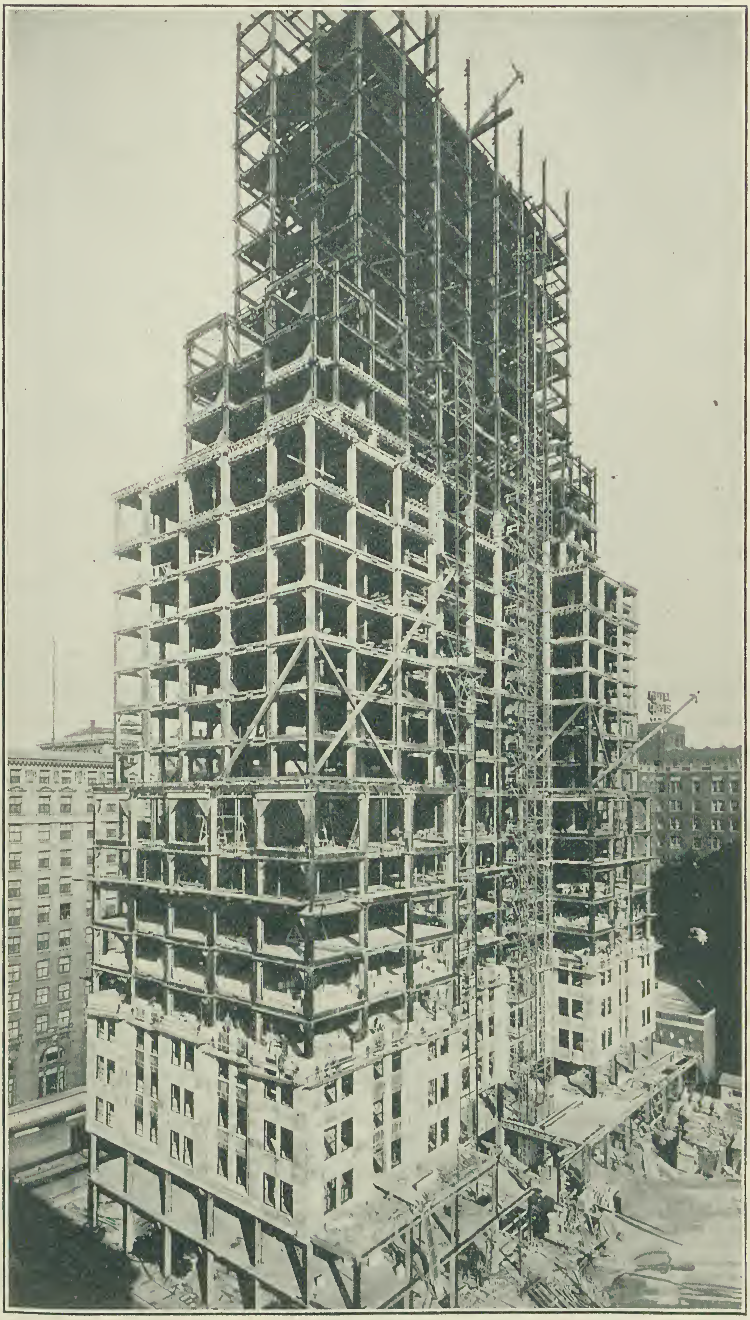
*Frame construction* includes buildings having the exterior walls or portions thereof of wood; also buildings with wooden framework veneered with brick, stone, terra cotta, or concrete; or covered with plaster, stucco, or sheet metal.

*Non-fireproof construction* includes all buildings having exterior masonry walls with floors and other interior construction wholly or in part of wood. If the floors and partitions of a non-fireproof building are of joist and stud construction the building is further classified as *ordinary construction*, but if the interior construction is of heavy timber properly designed and arranged the building is classified as *mill construction*. In the design of buildings of this type great care is used in avoiding unprotected openings which would enable fire to travel from one floor to another or from one room to another on the same floor. Stairways, elevator shafts and openings are carefully protected. Automatic sprinklers are usually installed. The following minimum sizes for timbers are required by the National Board of Fire Underwriters: Columns, 8 in. with rounded or chamfered corners; beams and girders 6 in. in either direction; floors, 3 in. thick with 1 in. finish flooring; roofs, $2\frac{1}{2}$ in. thick, and wood partitions, 2 in. thick.

The term *Slow-burning construction* is often taken as having the same meaning as Mill construction but sometimes a distinction is made between the two terms.

Heavy timber construction for buildings was developed in New England to decrease the fire hazard in the textile mills. On account of its use in the construction of mills this type of construction became known as Mill construction but since it is used for buildings other than mills and since other types of construction are also used for mills the term is unsatisfactory. The term Slow-burning construction which is extensively used is more desirable. The National Fire Protection Association recommends the more specific term, *Slow-burning, heavy timber construction.*

*Fireproof construction* includes buildings of masonry, steel, or reinforced-concrete construction. No woodwork or other combustible material may be used in the construction of fireproof buildings, except wooden finish flooring, interior doors and windows with their frames, trim and casings. Wooden strips, blocks or frames may be provided for nailing the flooring, casings, etc., if such strips, blocks or frames are embedded in an incombustible material. In the best class of fireproof buildings no wood whatever is used, the floors being of fireproof material and all doors, door and window frames, casings, etc., being of metal. Wire glass is used in the windows and in the case of severe exposure fire shutters may be required.



*The Lundoff-Bicknell Co., Contractors.* *Holabird and Root, Architects*

SKELETON CONSTRUCTION, PALMOLIVE BUILDING, CHICAGO, ILL.

All steel beams, girders, columns, and reinforcing bars must be protected from overheating in case of fire, by approved fireproofing materials, for steel loses its strength at high temperatures.

Buildings might also be classified according to type of construction into buildings of Bearing wall construction and buildings of Skeleton construction.

In *Bearing wall construction* the loads are transmitted to the foundation by walls.

In *Skeleton construction* all loads are transmitted to the foundation by a rigidly connected framework of metal or reinforced concrete, the enclosing walls and partitions being supported by girders at each story. See p. 7.

**Classification According to Use.** — Buildings may be classified according to use or occupancy into:

1. Public Buildings.
2. Residence Buildings.
3. Business Buildings.

1. *Public buildings* are considered as including all buildings or structures which are accessible to the public and in which people may congregate for civic, political, educational, religious, amusement, or transportation purposes; or in which they may be voluntarily or forcibly detained or housed for safety, punishment, observation or care. This class includes schools, churches, theaters, hospitals, court houses, railway stations, etc.

2. *Residence buildings* are considered as including all buildings in which sleeping accommodations (other than for janitor or watchman) are provided. This class includes apartment houses, dormitories, hotels, and dwellings.

3. *Business buildings* are considered as including all buildings and structures used for or adapted to the transaction of business, the operation of machinery, the manufacture or storage of machinery or materials, the housing of livestock, or for any other industrial purpose. This class includes such buildings as factories, office buildings, restaurants, warehouses, workshops and power plants.

**Relation Between Use, Height, Area, and Construction.** — The Building Code of the National Board of Fire Underwriters is used as a basis for the discussion under this heading and will illustrate the general principles involved. This code requires that all buildings over 4 stories or 55 ft. high be of fireproof construction except that business buildings over this height may be of mill construction. In certain classes of buildings fireproof construction is required for two- and three-story buildings and in some classes for all buildings, as will be explained later.

Cities usually set aside a certain area within which the building requirements are more severe than in other areas. This is done for the purpose of fire protection and the boundaries of this area are known as the *fire limits.*

Public buildings such as armories, asylums, detention buildings, hospitals, libraries, schools and theaters are required by this code to be fireproof for all heights, except that schools in which no pupils are accommodated above the second story may be of non-fireproof construction.

Public buildings such as amusement halls, churches, exhibition buildings, and public halls are required to have the floor over the cellar or basement which is nearest the grade level built of fireproof construction and all such buildings over 3 stories or 40 ft. in height are required to be of fireproof construction throughout.

Residence buildings such as dormitories, club houses, hotels, and lodging houses may be of frame construction if the height does not exceed 2 stories or 30 ft. Three-story buildings of this class must have a fireproof floor over the basement and buildings over 3 stories or 40 ft. in height must be fireproof.

Dwellings over 3 stories or 40 ft. in height must have a fireproof floor over the basement and those over 4 stories or 55 ft. in height must be of fireproof construction throughout.

Business buildings such as factories, office buildings, warehouses, stores, and workshops may be of ordinary construction if not over 4 stories or 55 ft. in height but such buildings over 2 stories or 30 ft. in height must have a fireproof floor over the lowest story. Buildings of this class which are over 4 stories or 55 ft. in height must be of fireproof or mill construction.

Frame buildings are not usually permitted within the fire limits but exceptions are made of such structures as small temporary buildings, sheds, and outhouses. In general, frame buildings are not permitted to be over 2 stories or 30 ft. in height but dwelling houses which are used for one family only may be 3 stories or 35 ft. in height. The ground area of frame buildings must not exceed 5,000 sq. ft. unless they are equipped with automatic sprinkler systems. The ground area may then be increased to 8,333 sq. ft., but in no case may the combined area of frame buildings, sheds, and outhouses located on any lot exceed 80 per cent of the lot area. In no case may a frame building with wooden siding be erected to extend within 5 ft. of the side or rear lot line, nor within 10 ft. of another building on the same lot.

The height limits given by the Building Code of the National Board of Fire Underwriters are summarized in that code as follows:

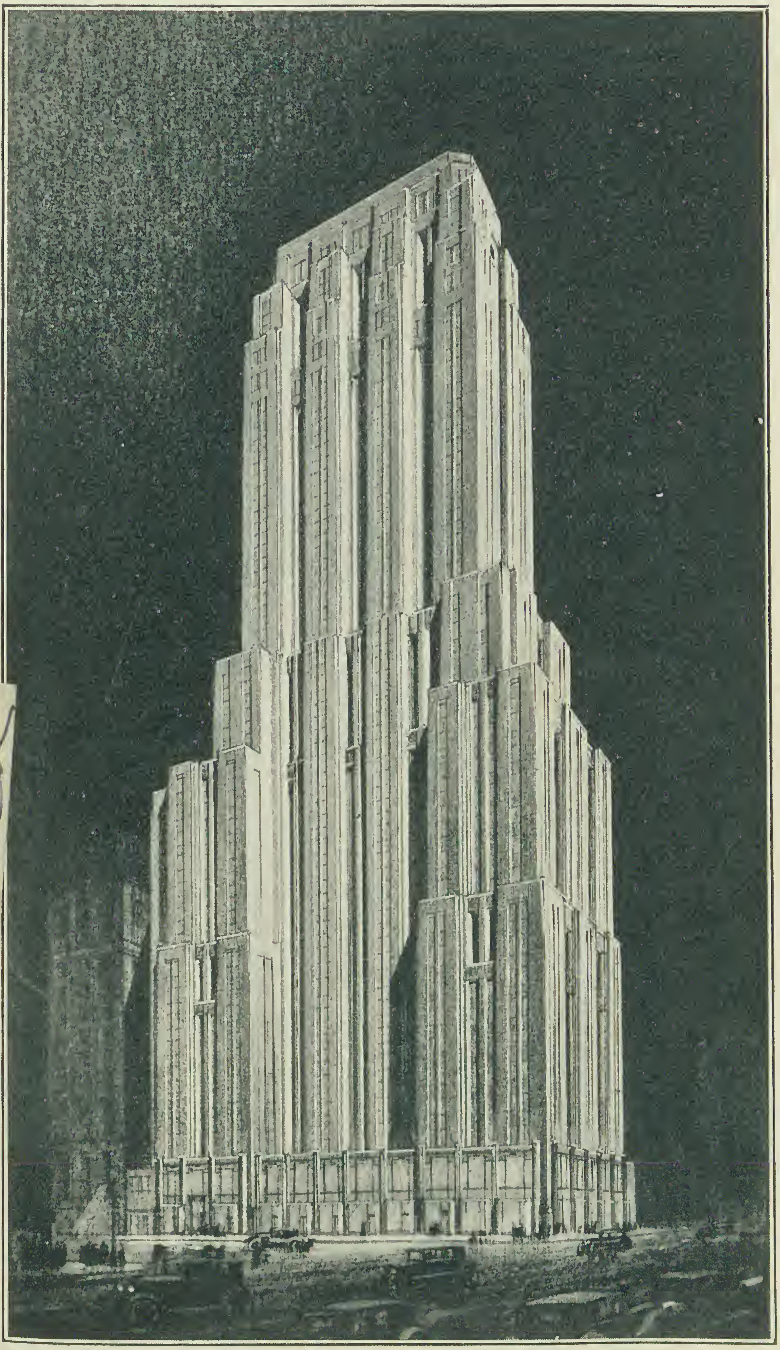
No building, or structure except church spires, water towers, smoke stacks or chimneys, shall exceed in height two and one-half times the width of the widest street upon which it fronts, nor shall it exceed the following limits:

| | *Stories* | *Feet* |
|---|---|---|
| Frame buildings used for purposes other than dwellings and tenements | 2 | 30 |
| Frame dwellings and tenements occupied by not more than two families | $2\frac{1}{2}$ | 30 |
| Frame dwellings occupied by not more than one family | 3 | 35 |
| Buildings having bearing walls of hollow terra cotta or concrete blocks | 3 | 40 |
| Non-fireproof buildings, ordinary construction | 4 | 55 |
| Non-fireproof buildings, mill construction: | | |
| Without sprinklers | 5 | 65 |
| With sprinklers | 6 | 75 |
| Fireproof buildings used for factories, stores, warehouses, or workshops | 7 | 85 |
| Fireproof buildings other than factories, stores, warehouses, or workshops | 10 | 125 |

The allowable floor area between exterior walls or fire walls is governed by the type of construction, the use of the building, the number of streets on which the building fronts. For instance, a non-fireproof building not exceeding 55 ft. in height and facing on one street may have an area of 5,000 sq. ft. but if it fronts on two streets it may have an area of 6,000 sq. ft. There is no restriction in area for fireproof office buildings. If automatic sprinklers are used the areas may be increased from 50 to 100 per cent depending upon the type of construction and use of the building.

In general, a building is not permitted to cover the entire lot area but uncovered spaces are provided to supply light and air to the building. These spaces must be open to the sky from the top of the second story window sills. The portion of the lot area which must be given over to uncovered spaces depends upon whether or not the building is on a corner lot, upon the use of the building, and upon its height. A hotel or similar building on a corner lot must devote 15 per cent of the total lot area to uncovered spaces if its height does not exceed 75 ft. or 6 stories with an increase of 2 per cent for each additional story up to 125 ft. in height. A hotel not on a corner lot must have uncovered spaces equal to 20 per cent of the total lot area if its height does not exceed 75 ft. and 25 per cent if its height is over 75 ft. The requirement for open spaces for buildings for other purposes are only about half as large as those for hotels or similar buildings.

The height restrictions in force in New York City are worthy of special attention on account of the effect they have had upon the architectural



*Holabird and Root, Architects*

PALMOLIVE BUILDING, CHICAGO, ILL. (11)

style of tall buildings throughout this country. The height to which a building may be carried is based primarily on the width of the street upon which it fronts, but portions of the building which are set back from the street line may be carried to greater heights based upon the amount of the set-back.

The city is divided into eight districts. In the district with the most severe restrictions, the height must not exceed one-quarter times the width of the street but for each 2 ft. that the building or portion of it sets back from the street line, 1 ft. may be added to the height of the building or the portion of it which is set back. In the district where the height restrictions are the most liberal, a building may be carried to a height of two and one-half times the width of the street and for each foot which the building or portion of it sets back from the street line, 5 ft. may be added to the height of the building or the portion of it which is set back. The requirements in the other six districts lie between those of the districts just given.

In all districts, if the area of the building is reduced so that, above a given level, it covers not more than 25 per cent of the area of the lot that portion of the building which is above such a level is not limited in height. The code contains several other exemptions from the height restrictions.

The restrictions on height were adopted to provide light and air for the buildings and the streets. Little thought was given to their effect on the appearance of the buildings but the "set-back" has led to the development of a style of architecture for tall buildings which is greatly superior in appearance to the styles which existed before the restrictions were adopted. The set-back is being used in all parts of the country even where the local codes do not have such requirements.

### ARTICLE 3. LOADS CARRIED BY BUILDINGS

The loads which buildings are called upon to carry may be divided into three groups: Dead load, live load, and lateral loads.

The *dead load* includes the weight of all parts of the building such as walls, permanent partitions, floors and roof. Temporary or movable partitions which may be moved to suit the needs of the occupants are usually classed as live loads.

The *live load* includes the weight of all of the furniture, equipment, occupants, stored material, snow which may accumulate on the roof of a building, and temporary or movable partitions.

The *lateral loads* include wind, earth pressure, water pressure, and earthquake shocks. Lateral loads are sometimes classed as live loads.

The minimum loads for buildings of various occupancies or uses are

specified by building codes. The requirements of these codes vary through a wide range for identical conditions. In order to bring about greater uniformity the Building Code Committee of the Department of Commerce has made a study of this problem. The results of this study are given in a report of the committee entitled "Minimum Live Loads Allowable for Use in Design of Buildings." The following minimum requirements for live floor and roof loads and for wind loads are abstracts from this report:

**Floor Loads.** —

| | Lb. per sq. ft. |
|---|---|
| *Human Occupancy:* | |
| Rooms of private dwellings, hospitals, hotels | 40 |
| Offices, rooms with fixed seats such as in churches, school class rooms and theaters | 50 |
| Aisles, corridors, lobbies, banquet rooms, assembly halls without fixed seats, gymnasiums | 100 |
| *Industrial and Commercial Occupancy:* | |
| Storage (general) | 250 |
| Storage (special) | 100 |
| Manufacturing (light) | 75 |
| Printing plants | 100 |
| Wholesale stores (light merchandise) | 100 |
| Retail salesrooms (light merchandise) | 75 |
| Stables | 75 |
| Garages for all types of vehicles | 100 |
| Garages for passenger cars only | 80 |
| Sidewalks, 800 lb. concentrated or | 250 |

The live loads for which each floor or differing parts thereof of a commercial or industrial building is designed shall be certified by the building official and shall be conspicuously posted in that part of each story where they apply, using durable metal signs. The occupant of the building shall be responsible for keeping the actual loads below the certified limits. Adequate measures shall also be taken by the building official to insure that these loadings are not exceeded.

**Roof Loads** (In pounds per sq. ft. of horizontal projection). —

| | |
|---|---|
| For slopes of 4 in. or less per ft. | 30 |
| For slopes of from 4 in. to 12 in. per ft. | 20 |

For slopes of over 12 in. per ft. no vertical load need be assumed but provision shall be made for a wind force acting normal to the roof surface of 20 lb. per sq. ft. of such surface.

**Reductions in Live Loads.** — Except in buildings for storage purposes the following reductions in assumed total floor live loads are permissible in designing all columns, piers or walls, foundations, trusses, and girders:

| | Per cent |
|---|---|
| Carrying one floor | 0 |
| Carrying two floors | 10 |
| Carrying three floors | 20 |
| Carrying four floors | 30 |
| Carrying five floors | 40 |
| Carrying six floors | 45 |
| Carrying seven or more floors | 50 |

[Any small area in a building may be subjected at any time to the specified floor load but, except in the case of buildings used for storage purposes, there is little possibility of a large area carrying a load of this same intensity. The average floor load will decrease as the area included becomes larger.]

For determining the area of footings the full dead loads plus the live loads, with the reductions figured as permitted above, shall be taken except that in buildings for human occupancy a further reduction of one-half the live load as permitted above may be used.

**Wind Load.** — For purposes of design the wind pressure upon all vertical plane surfaces of all buildings and structures shall be taken as not less than 10 lb. per sq. ft. for those portions less than 40 ft. above ground and not less than 20 lb. per sq. ft. for those portions more than 40 ft. above ground. (Special provision is made for sprinkler tanks, sky signs, etc.)

Where it shall appear that a building or structure will be exposed to the full force of the wind throughout its entire height and width the pressure upon all vertical surfaces thus exposed shall be taken as not less than 20 lb. per sq. ft. [There are wide variations in the wind load requirements of building codes throughout the country.]

**Earthquake Shocks.** — The Uniform Building Code prepared by the Pacific Coast Building Officials Conference suggests the following requirements for the codes of cities located within areas subjected to earthquake shocks:

The factors to be employed to fix the lateral force shall vary with the character of the foundation material and shall be as follows:

1. When the foundation rests upon material upon which a load of two or more tons per square foot is allowed, the horizontal force to be applied at any place shall be assumed as seven and one-half per cent of the total dead load plus the live load of the building above that plane.

2. When the foundation rests upon material upon which a load of less than two tons per square foot is allowed, the horizontal force to be applied at any plane shall be assumed as ten per cent of the total dead load plus the live load of the building above that plane. All buildings or pile foundations shall be included in this class.

## CHAPTER II

# BUILDING MATERIALS

### ARTICLE 4. GENERAL DISCUSSION

The materials which are considered in this chapter are those which are used in many parts of a building. Other materials whose use is limited to one part of a building are considered in the appropriate chapters.

Masonry materials such as brick, stone, hollow clay tile, concrete blocks and tile, architectural terra cotta and cast stone are considered in Chapter IV, on Masonry Construction. Flooring materials such as clay tile, magnesite composition, asphalt mastic, and linoleum are considered in Chapter IX. Roofing materials are considered in Chapter X, glass in Chapter XII, and painting materials in Chapter XV.

To assist in the understanding of the methods of manufacture of building materials some of the fundamental principles of chemistry will be explained in this article.

**The Elements, Compounds, and Mixtures.** — All substances are made up of about ninety elements. An *element* may be defined as a substance which cannot be separated by any known means into substances different from itself. If two or more substances are mixed together and can then be separated by mechanical means a *mechanical mixture* is formed but if they combine in definite proportions to form a homogeneous mass whose components cannot be separated mechanically a *chemical compound* is formed. *Alloys* and *solutions* are formed by mixing substances together to form other substances which are homogeneous and cannot be separated into their components mechanically, but these substances need not be in absolutely definite proportions and therefore are not chemical compounds.

**Atoms and Molecules.** — According to the atomic theory an *atom* is the smallest particle of an element which can exist either alone or in combination with similar particles of the same or of a different element. The atoms of one element have the power of attracting atoms of other elements to form *compounds.* The combination of atoms forms *molecules* which are the smallest particles of a compound which can exist. Given elements always combine in definite proportions when they form the same substance. For instance, when hydrogen and oxygen combine to form water, they always unite in the proportions of two atoms of hydrogen to one atom of oxygen. The weight of an atom

of oxygen is sixteen times as great as the weight of an atom of hydrogen; therefore, by weight, two units of hydrogen combine with sixteen units of oxygen to form eighteen units of water. The same elements may sometimes combine in different proportions to form different substances. For instance, one atom of carbon will combine with one atom of oxygen to form one molecule of carbon monoxide, and one atom of carbon will combine with two atoms of oxygen to form one molecule of carbon dioxide.

**Chemical Symbols, Formulas, and Equations.** — For convenience, each element is designated by a *symbol.* The elements which compose practically all building materials and the symbols for these elements are:

| | | | |
|---|---|---|---|
| Aluminum | Al | Nickel | Ni |
| Calcium | Ca | Nitrogen | N |
| Carbon | C | Oxygen | O |
| Chlorine | Cl | Phosphorus | P |
| Copper | Cu | Potassium | K |
| Hydrogen | H | Silicon | Si |
| Iron | Fe | Sulphur | S |
| Lead | Pb | Tin | Sn |
| Magnesium | Mg | Zinc | Zn |
| Manganese | Mn | | |

Compounds are designated by *formulas* formed by combining the symbols of the component elements. The number of atoms of each element in the molecule of the compound is indicated by a subscript figure. For instance, the formula for water is $H_2O$. This indicates that water is formed of a combination of hydrogen and oxygen in the proportions of two atoms of hydrogen to one atom of oxygen.

The changes which occur when elements or compounds combine are indicated by chemical *equations.* For instance, the equation for the chemical change which takes place when the elements hydrogen and oxygen combine to form the compound water is

$$2H + O = H_2O$$

A more complicated change takes place when the compound quicklime ($CaO$) absorbs the compound carbon dioxide ($CO_2$) from the air while setting to form the compound calcium carbonate. This is indicated by the equation

$$CaO + CO_2 = CaCO_3$$

One of the changes which takes place in a blast furnace in the manufacture of pig iron is the reaction of three molecules of carbon monoxide ($CO$) with one molecule of iron oxide ($Fe_2O_3$) to form three molecules of carbon dioxide ($CO_2$) and one molecule of iron (Fe) thus

$$3CO + Fe_2O_3 = 3CO_2 + Fe$$

In all cases the number of atoms of each element on one side of the equation must equal the number of atoms of that element on the other side; in other words, the equations must balance.

Many other details might be explained but enough has been given so that a general idea of the use of equations can be formed.

**Acids, Bases and Salts.** — Most compounds may be classed as acids, bases, or salts. *Acids* are compounds, containing hydrogen, which will react with the metallic oxides known as *bases* to form neutral compounds called *salts.*

Some of the common acids are: Hydrochloric ($HCl$), sulphuric ($H_2SO_4$), and nitric ($HNO_3$). Quicklime ($CaO$), magnesia ($MgO$) and potash ($K_2O$) are examples of bases. Common salt is sodium chloride ($NaCl$) and is formed by adding hydrochloric acid to the base soda thus:

$$Na_2O + 2HCl = H_2O + 2NaCl$$

**Common Compounds.** — The chemical name and chemical formula for some of the more common compounds used in building construction are:

| *Substance* | *Chemical Name* | *Formula* |
|---|---|---|
| Alumina | Aluminum oxide | $Al_2O_3$ |
| Carbonate of lime | Calcium carbonate | $CaCO_3$ |
| Quicklime | Calcium oxide | $CaO$ |
| Slaked lime | Calcium hydroxide | $Ca(OH)_2$ |
| Sulphate of lime | Calcium sulphate | $CaSO_4$ |
| Magnetite | Magnetite | $Fe_3O_4$ |
| Hematite | Ferric oxide | $Fe_2O_3$ |
| Litharge | Lead monoxide | $PbO$ |
| Red lead | Red lead oxide | $Pb_3O_4$ |
| White lead | Basic lead carbonate | $2PbCO_3.Pb(OH)_2$ |
| Magnesia | Magnesium oxide | $MgO$ |
| Magnesium carbonate | Magnesium carbonate | $MgCO_3$ |
| Manganese dioxide | Manganese dioxide | $MnO_2$ |
| Silica | Silicon dioxide | $SiO_2$ |
| Sulphur dioxide | Sulphur dioxide | $SO_2$ |
| Salt | Sodium chloride | $NaCl$ |
| Zinc white | Zinc oxide | $ZnO$ |
| Zinc sulphate | Zinc sulphate | $ZnSO_4.7H_2O$ |
| Muriatic acid | Hydrochloric acid | $HCl$ |
| Nitric acid | Nitric acid | $HNO_3$ |
| Sulphuric acid | Sulphuric acid | $H_2SO_4$ |
| Vinegar | Acetic acid | $HC_2H_3O_2$ |
| Carbonic acid gas | Carbon dioxide | $CO_2$ |
| Water | Water | $H_2O$ |

## ARTICLE 5. CEMENTING MATERIALS AND MORTARS

### Gypsum Plasters

**Raw Material.** — The basic material in all gypsum plaster is the mineral gypsum which occurs in three forms, *gypsum rock*, *gypsum earth* or *gypsite*, and *gypsum sand*. *Alabaster* is a pure form of gypsum.

When pure, gypsum is composed of one molecule of sulphate of lime and two molecules of water as indicated by the chemical formula ($CaSO_4 + 2H_2O$). Gypsum is rarely found in a pure state but contains clay, limestone, iron oxide and other impurities. Pure gypsum is a soft, white mineral.

**Classification.** — Gypsum plasters are divided into four classes:

1. Plaster of paris.
2. Cement, hard-wall, or patent plaster.
3. Flooring plaster.
4. Hard-finish plaster.

**Changes in Manufacture and Setting.** — When gypsum is heated to temperatures between 212 deg. fahr. and 400 deg. fahr. it loses three-fourths of the combined water as indicated by the equation:

$$(CaSO_4 + 2H_2O) + \text{Heat} = (CaSO_4 + \tfrac{1}{2}H_2O) + 1\tfrac{1}{2}H_2O$$

the one and one-half molecules of water being driven off as steam. The remaining product is *plaster of paris* if pure gypsum is used in the process, and *cement plaster*, or *hard-wall plaster* if certain impurities are present or are added, these impurities causing the product to set more slowly than the rapid setting plaster of paris. For a discussion of the various kinds of cement plaster see Article 80.

If gypsum is heated above 400 deg. fahr. practically all of the combined water is driven off as indicated by the formula:

$$(CaSO_4 + 2H_2O) + \text{Heat} = (CaSO_4) + 2H_2O$$

forming *dead-burned*, *hard-burned*, or *anhydrous* plaster. If pure gypsum is used the resultant product is known as *flooring plaster* but if certain substances, such as alum or borax, have been added *hard-finish plaster* is produced. *Keene's cement* is one variety of hard-finish plaster.

The setting of gypsum plasters is due to the recombination of the dehydrated lime sulphate, $CaSO_4$, or the partially dehydrated lime sulphate ($CaSO_4 + \frac{1}{2}H_2O$) with water to form the original hydrated sulphate ($CaSO_4 + 2H_2O$). The necessary water is added when the plasters are used.

**Methods of Manufacture.** — Plaster of paris and cement plaster are made by calcining or burning gypsum in large kettles or in rotary kilns. If kettles are used the gypsum is finely ground before burning, but for the rotary kilns the gypsum is crushed to a size of about one inch, the final pulverizing being accomplished after burning.

Flooring plaster is made by calcining pure gypsum in lump form in vertical kilns. After calcination the plaster is finely pulverized. The most common form of hard-finish plaster is Keene's cement. This material is formed by calcining lump gypsum, immersing in a 10 per cent alum solution, recalcining, and finally pulverizing to produce the finished product.

The time of set of cements or hard-wall plasters is regulated to suit the convenience of the workmen who are to use them. Ordinarily the setting must be delayed and therefore a *retarder* consisting of such materials as glue, sawdust, or blood, is added. If the time required for setting is too great, an *accelerator*, such as common salt, is used. Accelerators are not required in plasters for building purposes. The working qualities and sand-carrying capacity of cement or hard-wall plaster are improved by adding clay or hydrated lime by the manufacturers and their cohesiveness is increased by the addition of cattle hair or wood fiber. For use in localities where good sand is not available, plaster mixed with the proper amount of sand for use in plastering may be obtained from some manufacturers.

**Uses.** — Plaster of paris is used for ornamental castings, but on account of the rapidity with which it sets it is not suitable for use in a wall plaster or for mortar.

Cement or hard-wall plaster is very extensively used as a wall plaster for buildings but it will not withstand weathering action and is therefore not suitable for exterior use. Also blocks for use in fireproofing steel members and in constructing partitions, floors and roofs of buildings are made with cement plaster. It is also used in the manufacture of plaster board, which consists of a core of plaster, with a covering of cardboard, pressed into sheets $\frac{1}{4}$ in. and $\frac{3}{8}$ in. thick. Floor and roof slabs of skeleton steel construction are sometimes constructed of cement plaster and an aggregate reinforced with steel in a manner similar to reinforced concrete.

Flooring plaster is used to form the surface of floors. About 12 hours after the material has been placed it is pounded with wooden mallets and smoothed with trowels and forms a hard, durable surface. Flooring plaster is extensively used in Germany but is not used in this country. Hard-finish plasters are employed as wall plasters when a waterproof and unusually hard surface is desired. *Keene's cement* is the best known of these plasters. *Parian cement* is another form.

For a discussion of the use of gypsum plasters see Article 80.

Gypsum mortar for plastering is made by mixing cement plaster with from 1 to 3 parts of sand, depending on conditions. The wood-fibered plaster may be used without sand or may be mixed with equal parts of sand. Gypsum mortar is always used for laying gypsum partition blocks, a 1–3 mixture being the most common.

## Quicklime

**Definition.** — *Quicklime* is the product resulting from the burning of limestone at a temperature sufficiently high to drive off the carbon dioxide.

**Raw Materials.** — Pure quicklime is calcium oxide ($CaO$) and is obtained from pure limestone ($CaCO_3$) but commercial quicklime contains varying amounts of magnesium oxide ($MgO$) resulting from the presence of magnesium carbonate ($MgCO_3$) in the raw material. The chemical formula for the raw material used in lime manufacture is

$$x\,CaCO_3 + y\,MgCO_3$$

$x$ and $y$ being variables. Impurities such as silica, alumina, and iron are always present.

**Classification and Grades.** — Quicklime is divided into four classes depending on the relative amounts of calcium oxide and magnesium oxide present: *High-calcium,* containing 90 per cent or over of calcium oxide; *calcium,* containing from 75 to 90 per cent of calcium oxide; *magnesian,* containing between 25 to 40 per cent of magnesium oxide; *high-magnesian* or *dolomitic,* containing a high percentage of magnesium oxide. Common practice recognizes the division of quicklime into only two classes: calcium limes and magnesian limes.

Quicklime is divided into two grades: *Selected,* which is a well-burned lime free from ashes, core, clinker, and other foreign material; and *Run-of-kiln,* which is well-burned lime without selection.

Hydrated lime is furnished in two classes according to plasticity. *Masons' hydrated lime* has lower plasticity than finishing hydrated lime and is used for mortar and for the scratch and brown coats of plaster. *Finishing hydrated lime* has high plasticity and is used for the finish coat of plaster in addition to the uses made of masons' hydrated lime.

**Manufacture.** — Quicklime is made by burning limestone in kilns at a temperature sufficient to drive off the carbon dioxide. If pure limestone is used the process may be shown by the following formula:

$$CaCO_3 + \text{Heat} = CaO + CO_2$$

Calcium oxide ($CaO$) is a white solid and carbon dioxide ($CO_2$) is a gas. If magnesium carbonate is present a corresponding reaction occurs leaving magnesium oxide and driving off carbon dioxide gas.

The fuel used in the process is coal.

**Slaking.** — In preparing lime mortar, quicklime is mixed with water forming calcium hydroxide, $Ca(OH)_2$. This is a fine white powder but an excess of water is always used, forming a paste, called lime paste or *lime putty*. The chemical change which occurs in slaking pure quicklime is shown by the formula:

$$CaO + H_2O = Ca(OH)_2$$

A corresponding reaction occurs when magnesium oxide is present. The form of lime known as *hydrated lime* is simply the hydroxide formed by adding water to quicklime at the place of manufacture instead of on the job. While this change is occurring a considerable amount of heat is generated and a marked increase in volume occurs.

The calcium limes slake more rapidly than the magnesium limes and give off a greater amount of heat. For quick-slaking limes, the lime should be added to the water and when escaping steam appears the lime should be hoed and enough water added to stop the steaming. For medium-slaking and slow-slaking lime, add the water to the lime. Care must be taken to avoid cooling slow-slaking lime and in cold weather it may be necessary to heat the water. There is little danger that too much water will be added to the quick-slaking calcium limes but an excess of water may cause magnesium lime to be "drowned." If too little water is added to either calcium or magnesium limes they may be "burned." In case of either burning or drowning, a part of the lime is spoiled for it will not harden and the paste is not as viscous and plastic as it should be.

Tests by the National Lime Association indicate that from 4.5 to 8.5 cu. ft. of putty can be made from an 180-lb. barrel of quicklime containing 3.1 cu. ft., the quantity depending upon the kind of lime and the skill used in slaking.

Slaked lime should be allowed to age for 2 weeks before it is used for plastering but 24 hours may be sufficient if the lime is to be used for masons' mortar.

In making putty or paste from hydrated lime, the lime is sifted slowly into the water, the mixture being constantly stirred. The putty is allowed to age or soak for at least 24 hours. The ageing process increases the workability and sand-carrying capacity of the putty. Since hydrated lime has been slaked before shipping the increase in volume while

the putty is being made is small. A sack of hydrated lime weighing 50 lb. and containing 1 cu. ft. will make about 1.1 cu. ft. of lime putty.

**Setting.** — In setting, the excess water is evaporated and the calcium hydroxide combines with carbon dioxide from the air to form calcium carbonate as shown by the formula:

$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O$$

A corresponding reaction occurs when magnesium hydroxide is present. The absorption of carbon dioxide occurs very slowly and in heavy masonry walls the setting may never occur.

The term "air-slaked" is often applied to quicklime which has become slaked by absorbing moisture from the atmosphere, but the process does not stop when this change has occurred for the hydroxide thus formed absorbs carbon dioxide forming calcium carbonate, which has lost its cementing properties. To protect quicklime from "air-slaking" it is stored in barrels. Ground lime does not air-slake as readily as lump lime because the outer layer air-slakes and protects the remainder. It can therefore be shipped in bags.

**Uses.** — Lime putty mixed with 2 or 3 parts by volume of sand to form a mortar is used in building masonry walls and for plastering walls and ceilings. For a discussion of the use of lime in plastering see Article 80. Hydrated lime is furnished in 100-lb. cloth sacks and 50-lb. paper sacks and lump lime in 180- and 280-lb. barrels.

## Portland Cement

**Definition.** — Portland cement is the product obtained by finely pulverizing the clinker produced by calcining to incipient fusion an intimate and properly proportional mixture of argillaceous and calcareous materials with no additions subsequent to calcination excepting water and calcined or uncalcined gypsum.[1]

**Raw Materials.** — The materials necessary in the manufacture of portland cement are lime, silica, and alumina. These materials are obtained by mixing an impure limestone, containing considerable clay, with pure limestone; by mixing limestone and clay or shale; or by mixing limestone and blast-furnace slag. These materials must be mixed in the proper proportions as determined by chemical analysis.

**Manufacture.** — The steps in the manufacture are as follows:[2]

1. Crushing the raw materials.
2. Drying the raw materials.
3. Grinding the raw materials.

[1] Specifications of the American Society for Testing Materials.

[2] Similar to outline in Johnson's Materials of Construction, John Wiley & Sons, Inc., 1925.

4. Proportioning the raw materials.
5. Pulverizing the raw materials.
6. Burning to form clinkers.
7. Cooling the clinkers.
8. Adding the retarder to control the time of set.
9. Pulverizing the clinker to produce cement.
10. Seasoning of the cement.

The strength of concrete increases with the fineness of grinding of the cement. Specifications require that not more than 22 per cent of the cement be retained on a sieve having 200 meshes per in.

The chemical changes which occur in the manufacture of portland cement are too complex to consider here, but consist essentially of the combination of lime and magnesia with silica, alumina, and ferric oxide to form silicates, aluminates, and ferrites.

**Setting and Hardening.** — When water is added to portland cement a paste is formed. This paste soon loses its plasticity and begins to harden due to complicated chemical changes which are started when the water is added. The process of setting is divided into two stages by specifications, i.e.; *initial set* and *final set.* The progress of the setting is measured by the penetration of weighted needles constructed according to standard specifications. Initial set should not take place in less than 45 minutes and final set should not require more than 10 hours. The hardening of portland cement continues for many months.

**Uses.** — Portland cement is used as a cementing material in mortar and concrete. In making mortar 1 part of cement is mixed with 3 or 4 parts of sand and the required amount of water. Cement mortar is stronger, more durable, and more fire-resistant than lime mortar.

Lime mortar works better under the trowel than cement mortar, but cement mortar may be improved in this respect by replacing about 15 per cent of the cement with lime.

Concrete is made by mixing 1 part of cement with from 1 to 3 parts of sand, and from 2 to 6 parts of gravel, or crushed rock, together with the required amount of water as described in Article 6.

## ARTICLE 6. CONCRETE

Concrete is made by mixing portland cement and water with inert materials such as sand, gravel and crushed rock, which are called *aggregates.* The cement and water form a paste which, due to chemical action, sets and hardens, binding the inert materials together and forming a rock-like mass. In order to secure a durable concrete of desired strength and possessing other necessary characteristics at a minimum

cost, extreme care must be exercised in selecting the materials, in mixing them in the proper proportion, in placing the concrete in the forms, and in protecting the concrete after it has been placed.

**Materials.** — The portland cement used in concrete is usually required to conform to the "Specifications and Tests for Portland Cement" of the American Society for Testing Materials. The water should be clean and free from injurious amounts of oils, acid, alkali, organic matter, or other deleterious substances.[1]

The inert material, called aggregate, should be clean, strong, and durable. It is divided into two classes according to size: fine aggregate, and coarse aggregate. Aggregate passing a sieve with $\frac{1}{4}$ in. openings is usually classed as *fine aggregate* and that which will not pass this sieve is classed as *coarse aggregate.* The fine aggregate and the coarse aggregate should be composed of particles graded in size from the smallest to the largest included in each. The grading requirement depends upon the type of work and upon the materials available.

The fine aggregate is usually sand and the coarse aggregate is gravel or crushed rock. When concrete of light weight is desired and strength is not an important factor cinders from anthracite coal are frequently used as aggregate. Cinders containing sulphur should not be used because the sulphur forms sulphuric acid which attacks the reinforcing bars, structural steel, piping, etc., embedded in concrete. Blast-furnace slag is sometimes used as coarse aggregate.

**Proportioning.** — The proportioning of the materials used to form concrete has been the subject of much study and research and many methods have been used. A method which has been in vogue for a number of years calls for *arbitrary proportions* which do not take into account the characteristics of the materials and pays little attention to the amount of water used. For example, a 1:2:4 concrete might be specified. This consists of 1 part of cement to 2 parts of fine aggregate and 4 parts of coarse aggregate, all measurements being by volume. On account of its simplicity this method is still extensively used.

At the present time emphasis is being placed upon the *water-cement ratio theory* of proportioning developed by Professor D. A. Abrams. According to this theory, for a given set of conditions and materials, the strength and other desirable qualities of concrete are determined by the amount of mixing water provided that the mixture is workable and plastic and clean, sound aggregates are used. The ratio of the amount of water to the amount of cement is called the *water-cement ratio* and is usually expressed in gallons of water per sack of cement. The pro-

[1] 1924 Joint Committee Report on Concrete and Reinforced Concrete.

portion of aggregate used affects the consistency but has practically no effect upon the strength. If a small amount of aggregate is added to a given quantity of cement paste a concrete of fluid consistency will be formed. As the amount of aggregate is increased the concrete becomes plastic up to a certain limit and finally becomes stiff. The amount of aggregate which may be added depends upon the character of the work and upon the physical characteristics of the aggregate. Concrete which is to be placed in large masses with a small amount of reinforcing can be a relatively dry or stiff mix with a larger amount of aggregate in proportion to the cement than concrete which is to be placed in thin walls with a network of closely spaced reinforcing bars, the water-cement ratio and therefore strength of the concrete per unit of area being the same in each case.

The amount of aggregate which may be added to a given amount of cement paste with a fixed water-cement ratio to produce a concrete of a certain consistency or workability depends upon the grading of the fine and the coarse aggregate and upon the proportion of the fine to the coarse aggregate. In general, both the fine aggregate and the coarse aggregate should be well graded and there should be considerably more coarse aggregate than fine aggregate. Any surface water which is on the aggregates should be taken into account in determining a water-cement ratio and deductions should be made for the water absorbed by the aggregates. Methods have been devised to accomplish these results.

In using the water-cement ratio theory, the water-cement ratio which will give the desired strength is determined by tests, or tables which represent average conditions may be used. The table given on p. 26 is taken from the Standard Building Regulations for Reinforced Concrete (1928) prepared by the American Concrete Institute and will serve as an example. By consulting this table it will be noticed that the strength of plastic concrete is the same as that for moderately wet concrete for the same water-cement ratio but the plastic concrete has a higher proportion of aggregate to cement than the moderately wet concrete.

The value of the water-cement ratio theory is summarized by Arthur R. Lord[1] as follows: "While the water-cement ratio is of primary importance, as indicating strength of workable mixtures, this relation is not the same for all cements and all aggregates nor all gradations of aggregate from the same source. It must be determined in advance for the particular materials to be used."

[1] Notes on Concrete — Wacker Drive, Chicago. American Concrete Institute, *Proceedings*, Vol. 23.

Assumed Strength of Concrete Mixtures

| Water-Cement Ratio | Approximate Mix | Assumed Compressive Strength at 28 Days |
|---|---|---|
| | *Plastic Concrete* | Lb. per Sq. In. |
| $8\frac{1}{4}$ | 1 : 7 | 1,500 |
| $7\frac{1}{2}$ | 1 : 6 | 2,000 |
| $6\frac{3}{4}$ | 1 : $5\frac{1}{4}$ | 2,500 |
| 6 | 1 : $4\frac{1}{2}$ | 3,000 |
| | *Moderately Wet Concrete* | |
| $8\frac{1}{4}$ | 1 : $6\frac{1}{2}$ | 1,500 |
| $7\frac{1}{2}$ | 1 : $5\frac{1}{2}$ | 2,000 |
| $6\frac{3}{4}$ | 1 : $4\frac{3}{4}$ | 2,500 |
| 6 | 1 : 4 | 3,000 |

The water-cement ratio is expressed in gallons of water per 94-lb. sack of cement. The approximate mix is expressed in parts of cement to the sum of the parts of fine and coarse aggregate measured separately.

**Mixing and Placing.** — Except on small jobs, concrete is most economically mixed in machines called concrete mixers consisting of rotating drums into which the materials are charged. These drums are provided with baffle plates which assist materially in the mixing process. Mixers may be of the batch type or the continuous type. In the case of batch mixers all the materials for a batch of concrete are charged into the drum. When the mixing process is completed the batch of concrete is discharged before the materials for another batch are placed in the mixer. Continuous mixers are so designed that the materials are charged into the mixer continuously and the concrete is discharged in a steady stream. Most specifications require that batch mixers be used, the product being more reliable than that of continuous mixers.

The quality of concrete is affected by the length of time the materials are mixed. The effect of the time of mixing is very marked up to about 1 minute but the improvement in quality gained by further mixing is so small that specifications do not usually require a longer mixing period. Where the best results are desired the mixing period should be from $1\frac{1}{2}$ to 2 minutes. The mixing period is counted from the time all of the materials are in the mixer. Since the time devoted to mixing each batch sets the pace for the concrete work there is always a strong tendency to reduce the mixing period below the specified minimum. Some mixers are provided with automatic devices which lock the discharge levers until the specified mixing time has elapsed.

If concrete is to be mixed by hand, the cement and fine aggregate should first be mixed to a uniform color on a watertight platform. The water and coarse aggregate should then be added and the entire mass be turned at least three times or until a homogeneous mixture of the required consistency is obtained.

After concrete has partially set it should not be remixed with or without the addition of water or other materials. This is known as *retempering.*

The common methods of conveying concrete from the mixer to the place of final deposit are by wheelbarrow, by two-wheel concrete carts, and by means of chutes or spouts. If the concrete is to be elevated this may be done by placing the filled wheelbarrows or concrete carts on a construction hoist or the mixer may discharge into a skip which is hoisted to the desired level and discharged into a hopper or a bin from which the concrete is removed by wheelbarrows or concrete carts. If chutes are to be used the concrete is elevated by a skip to a hopper from which it runs down chutes to its place in the forms. Wheelbarrows have less capacity than concrete carts but may be pushed up steeper grades and may be operated over a narrower and less substantial runway than the two-wheel carts. The equipment costs are high when chutes are used but on large jobs the reduction in labor costs may make this method the most economical. In order to secure a mixture which will flow easily in the chutes there is a tendency to use too much water in the mixture, which always reduces the strength of the concrete. The same result can be accomplished without a sacrifice in strength by using the water-cement ratio for the strength desired and reducing the amount of aggregate. This increases the cost of materials, because of relatively greater quantity of cement, but maintains the strength of the concrete.

While the concrete is being placed in the forms it should be worked with suitable tools to insure that it is thoroughly compacted, that it reaches all parts of the forms, and that it completely surrounds all reinforcing steel. If too much mixing water is used, an extremely fine material with little or no hardness will collect on the surface of freshly deposited concrete. This is called *laitance.* It has little strength and readily disintegrates.

When it is necessary to deposit concrete under water, suitable methods and equipment should be used to prevent the washing of the cement from the mixture. This may be done by using a *tremie* or a *drop-bottom bucket.* A tremie is a large pipe temporarily sealed at one end. It is held in a vertical position with sealed end down, filled with concrete, and lowered through the water so that its lower end rests on the bottom and its upper end is above the surface of the water. The seal at the lower

end is then removed and the tremie is raised an amount just sufficient to permit the concrete to flow out of the bottom at the rate at which it may be conveniently added at the top. The flow may be stopped at any time by forcing the tremie down into the concrete which has been placed. If the concrete is permitted to flow out so rapidly that the tremie is emptied, it is necessary to raise the tremie, seal the lower end again and repeat the operation as outlined above. By means of the tremie, concrete is built up from the bottom of the excavation containing water but does not fall through the water. There should be no opportunity for the water to wash the cement from the concrete mixture. The Joint Committee Report (1924) gives the following methods for sealing the bottom of the tremie:

(1) Place the lower end in a box partly filled with concrete, so as to seal the bottom, then lower into position; (2) plug the tremie with cloth sacks or other material, which will be forced down as the pipe is filled with concrete; (3) plug the end of the tremie with cloth sacks filled with concrete.

A drop-bottom bucket for placing concrete in water is so arranged that the bottom doors are automatically opened as soon as the bucket strikes the surface on which the concrete is to be placed. The bucket is filled with concrete and slowly lowered through the water into position and discharged.

**Curing.** — The strength of concrete is very materially affected by the treatment which it receives during the setting and hardening period. Some of the chemical reactions take place very slowly and if the concrete dries out before they have been completed the strength does not develop to the extent that it will if water is present. It is essential that surfaces which are exposed should be kept moist for at least seven days after the concrete is deposited. This may be accomplished by sprinkling such surfaces once or twice a day or by covering them with sand or sawdust and keeping these materials moist.

**Depositing in Cold Weather.** — The chemical reactions which occur in setting and hardening are retarded or halted at low temperatures. Specifications state that concrete should be maintained at a temperature of at least 50 deg. fahr. for not less than 72 hours after placing.[1] Concrete which has been frozen and is subsequently thawed out suffers greatly in quality, even though the setting and hardening process continues after thawing. By heating the materials before mixing and by keeping the concrete warm after placing it is possible to secure satisfactory results even in very cold weather. The freezing point can be lowered somewhat by using salt in the mixture but this may cause a

[1] 1924 Joint Committee Report.

considerable reduction in strength, corrosion of reinforcement, and efflorescence (See Article 19).

### REFERENCES

1924 Report of the Joint Committee on Specifications for Concrete and Reinforced Concrete. Proposed Standard Building Regulations for Reinforced Concrete, American Concrete Institute. Concrete Primer, by F. R. McMillan, *Proceedings* of American Concrete Institute Vol. 24.

## ARTICLE 7. PIG IRON, CAST IRON, AND WROUGHT IRON

### Pig Iron

**Definition, Composition, and Uses.** — *Pig iron* may be defined as the product obtained by the reduction of iron ores in the blast furnace. It contains 91 to 94 per cent of iron; 3 to 4 per cent of carbon; 0.5 to 3.0 per cent of silicon; 0.04 to 2.00 per cent of phosphorus; and less than 0.065 per cent of sulphur.[1]

Pig iron may be used directly in making castings but its most important use is in the manufacture of cast iron, wrought iron, and steel where it may be used in a molten state direct from the blast furnace or in the form of *pigs* which are castings made from the pig iron as it is drawn from the furnace.

**Raw Materials.** — The raw materials used in the manufacture of pig iron are: The iron ores which furnish the iron; the fuel which furnishes the heat and the reducing agent; the flux which provides a fusible slag which carries off ash of the fuel and some of the impurities of the ore; and air which supplies the oxygen for the combustion of the fuel.

Iron ores of commercial importance may be divided into four classes: iron oxides, iron carbonates, iron silicates, and iron sulphides; only the oxides are of importance in this country. The oxides of iron used in the manufacture of pig iron are:

*Hematite*, $Fe_2O_3$, containing about 70 per cent iron when pure;

*Limonite*, $Fe_2O_3$, n.$H_2O$, which is hydrated hematite containing about 60 per cent iron when pure;

*Magnetite*, $Fe_3O_4$, containing about 72 per cent iron when pure.

Impurities in the ore, such as sand and clay, are called the *gangue*.

The fuel has two functions in the manufacture of pig iron: the furnishing of the necessary heat and the supplying of the reducing agent to combine with the oxygen of the ore. The fuels used are coke, coal and charcoal. On account of its porosity and resistance to crushing, coke is

[1] The Making, Shaping, and Treating of Steel, by Camp and Francis, published by the Carnegie Steel Co.

superior to coal and charcoal and is usually used. A small amount of charcoal iron is produced in this country; because of its purity it sells for a higher price than ordinary pig iron.

The functions of a *flux* are to make the impurities in the ore and fuel, such as silica and alumina, more easily fusible and to provide a fusible slag in which these and other impurities may be carried off. The flux used in the blast furnace is usually limestone, which, when pure, is calcium carbonate and has the chemical formula $CaCO_3$ although a considerable amount of magnesium carbonate, $MgCO_3$, is commonly present.

**The Blast Furnace.** — The blast furnace is a structure from 90 to 100 ft. in height, approximately cylindrical in shape, built of fire brick, enclosed more or less completely in a steel shell. The furnace is divided into three main parts: the *hearth,* or *crucible,* the *bosh,* and the *stack* as shown diagrammatically in Fig. 1.

The hearth is provided with an *iron notch* and a *cinder notch* through which the iron and slag are periodically removed. Just below the bosh a ring of from 10 to 16 *tuyeres* penetrate the lining. The air necessary for the process is blown through these tuyeres, which are all connected to the *bustle pipe* which encircles the furnace and which is in turn connected to the hot-blast stoves, which heat the air, and finally to the blowing engines which provide the air at a pressure of from 15 to 30 lb. per sq. in.

At the top of the furnace there is a device which permits the raw material to be charged into the furnace but prevents the escape of the gases. These gases are heated to a very high temperature and contain a large amount of carbon monoxide (CO) which is combustible. In the early days these gases were permitted to burn as they left the furnace, but now they are used in the hot-blast stoves, under steam boilers, and in internal-combustion engines. This results in a considerable saving in fuel. The larger furnaces of the present time have a capacity of 600 tons of pig iron per day.

**Operation.** — A blast furnace is operated continuously by charging the *burden,* which consists of ore, fuel, and flux in proper proportions, in the top of the furnace and drawing off the slag and iron at the bottom, the slag being tapped at intervals of about 2 hours and the iron at intervals of about 5 hours. The iron may be used in the molten state in the manufacture of wrought iron or steel or may be cast into bars called *pigs* for subsequent use.

**Chemical Changes.** — Air contains about one part of oxygen to four parts of nitrogen and other inert gases. The air enters the blast furnace through the tuyeres at a temperature of about 1000 deg. fahr. and a pressure of from 15 to 30 lb. per sq. in. It immediately comes into con-

tact with hot coke and the oxygen of the air combines with the carbon of the coke forming carbon dioxide, thus:

$$C + O_2 = CO_2 \tag{1}$$

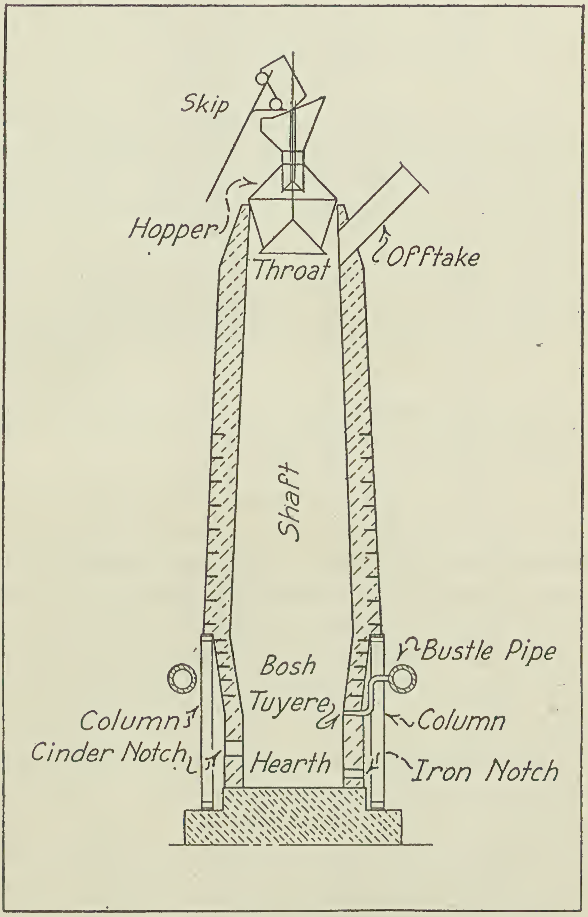



FIG. 1. Blast Furnace

On account of the excess of carbon which exists, the carbon dioxide is reduced to carbon monoxide (CO) thus:

$$CO_2 + C = 2CO \tag{2}$$

The ore as it moves down through the furnace encounters this carbon monoxide, which is a powerful reducing agent, and the following reactions result, the first occurring near the top of the furnace at a temperature of approximately 600 deg. fahr. and the last, in the lower part

of the stack at a temperature of about 1400 deg. fahr.:

$$2Fe_2O_3 + 8CO = 4Fe + 7CO_2 + C \tag{3}$$

$$3Fe_2O_3 + CO = 2Fe_3O_4 + CO_2 \tag{4}$$

$$Fe_3O_4 + CO = 3FeO + CO_2 \tag{5}$$

$$FeO + CO = Fe + CO_2 \tag{6}$$

Reactions (1) and (3) produce most of the heat required by the other reactions and to dry the raw materials, to decompose the limestone, to flux the impurities, and to melt the iron and slag. The temperatures in the furnace increase from about 500 deg. fahr. at the top to about 3600 deg. fahr. in the crucible.

Other changes occur but they are too confusing to consider here. However, it may be well to mention that the heated coke acts as a reducing agent in much the same manner as the carbon monoxide considered above.

The limestone in the charge breaks up into calcium oxide and carbon dioxide at about 1600 deg. fahr.; thus:

$$CaCO_3 = CaO + CO_2 \tag{7}$$

the $CO_2$ being reduced to CO when it encounters the hot coke. At about this same temperature the iron, which is in a spongy form, absorbs carbon from the coke. This lowers its melting point and it becomes fluid.

At the top of the bosh, the lime (CaO) combines with some of the gangue, a little unreduced iron oxide, and manganese oxide from the ore and forms slag which, with the molten iron, runs down through the coke to the hearth where the slag and the molten iron separate into two layers due to the difference in their densities, the slag — being the lighter — remaining on top.

In the hearth, part of the oxides of manganese ($Mn_3O_4$), silicon ($SiO_2$) and phosphorus ($P_2O_5$) are reduced by the carbon of the coke, which extends through to the bottom of the furnace, and join the iron. The remainder of the oxides are not so acted upon, and are found in the slag. All of the phosphorus present in the charge will be found in the iron but the amounts of silicon and manganese in the pig iron will depend upon furnace conditions. Sulphur is introduced into the blast furnace mainly as an impurity in the coke in the form of iron sulphide. Some of this reacts with the lime forming calcium sulphide and joins the slag but the remainder is found in the iron, for iron sulphide is soluble in iron. Conditions which tend to decrease the amount of sulphur present in the iron also tend to increase the amount of silicon.

## Cast Iron and Malleable Cast Iron

**Production.** — Cast iron is manufactured by remelting pig iron and pouring it into molds to form castings of the desired shape when the metal solidifies in cooling. Scrap iron, consisting chiefly of discarded castings, is used with the pig iron because it is less expensive than pig iron. No chemical changes of importance take place during the process of remelting.

**Molds and Patterns.** — The process of making castings is called *iron founding.* The molds are made of sand; the impressions in the sand are usually made by *wood patterns.* In *loam molding* no pattern is used, the impression being formed in the sand by hand or machine. Patterns must be slightly larger than the objects to be cast, to allow for the shrinkage of the metal in cooling. Vertical surfaces must be slightly tapered to facilitate the withdrawal of the pattern from the mold. This taper is called *draft.*

**Gray and White Cast Iron.** — When molten cast iron solidifies, the carbon which is present remains combined with the iron as *carbide of iron* ($Fe_3C$) or may separate from the iron as *graphite.* White cast iron contains carbon chiefly in the combined state. It has a white metallic fracture and is very hard and brittle. Gray cast iron contains carbon chiefly in the form of graphite mechanically mixed with the iron but some carbon is present in the combined state. It has a gray, crystalline fracture and is not so hard and brittle as white cast iron. The graphite in cast iron is in the form of flakes which reduce its strength very materially. Slow cooling and the presence of silicon tend to increase the amount of graphite in cast iron whereas rapid cooling and the presence of manganese and sulphur tend to hold the carbon in the combined state. Cast iron increases in strength as the amount of combined carbon is increased up to about 1.2 per cent, further increases causing a loss of strength. The hardness and brittleness increase as the amount of combined carbon is increased. In general, cast iron has a high compressive strength and a low tensile strength.

**Chilled Castings.** — Chilled castings are produced by using molds with certain surfaces made of iron. The iron which comes in contact with these surfaces is therefore cooled suddenly and the carbon in the iron remains in a combined state ($Fe_3C$) for a certain depth, forming white cast iron which is very hard. The remainder of the iron cools naturally and forms gray cast iron which is not so hard but is less brittle. Surfaces of cast iron which are subject to wear are often chilled to increase their life.

**Malleable Cast Iron.** — Castings made of white cast iron may be made malleable and ductile by subjecting them to an annealing process

which converts the combined carbon into free carbon in a very finely divided state. The annealing may be accomplished by packing the castings in some inert material such as sand or clay and heating to a red heat which is maintained for several days, after which they are slowly cooled.

Better results may be secured by packing the castings in an oxidizing material such as iron oxide. The oxide draws the carbon from the castings to a depth of $\frac{1}{16}$ of an inch or more, forming a skin of soft iron on the castings in addition to converting the combined carbon in the body of the castings into free carbon.

White cast iron is used so that the free carbon will all be in the form of very minute particles evenly distributed throughout the castings and not in the form of large flakes which have such a weakening effect on gray cast iron.

Malleable castings are used for small articles such as builders' hardware. Malleable iron washers are quite extensively used in timber construction.

## Wrought Iron

**Manufacture.** — Wrought iron is made by melting pig iron in a reverberatory furnace the hearth of which is lined with iron oxide as shown diagrammatically in Fig. 2. The carbon, silicon, manganese, phosphorus,

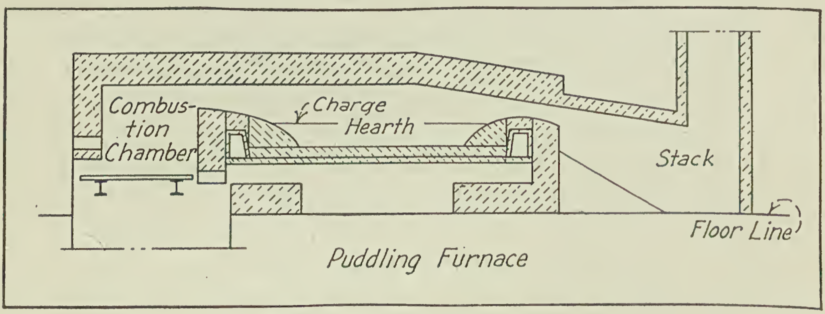



FIG. 2. Puddling Furnace

and sulphur in the molten pig iron come in contact with the oxygen in the lining of the hearth and in the air and become oxidized forming a slag on top of the iron. As the iron becomes purified its melting point is raised above the temperature of the furnace so that it assumes a pasty form. The iron in this condition is worked together in the hearth to form *puddle balls* which are removed from the furnace by hand. These balls contain a considerable amount of slag, most of which is expelled by squeezing, hammering, and finally rolling to form *muck bars.* These

bars are piled, heated to a welding temperature, and rolled to form *merchant bars* which are the finished product.

**Properties and Uses.** — Wrought iron is composed of very pure iron mechanically mixed with a small amount of slag. The rolling process has elongated the particles of iron and slag which existed in the puddle ball so that a fibrous structure is produced. The properties of wrought iron correspond to those of pure iron which is tough, ductile, easily welded, and comparatively low in tensile and compressive strength. It is superior to ordinary steel in resisting corrosion. In building construction, wrought iron is used for pipe and for ornamental iron work where welding is involved.

## ARTICLE 8. BESSEMER AND OPEN-HEARTH STEEL

**Comparison of Steel with Other Ferrous Products.** — The various methods and processes for manufacturing steel have as their primary object the reduction of the amount of carbon present in pig iron, but the amount of phosphorus, sulphur, manganese, and silicon is also controlled.

Steel differs in physical properties from pig iron, and cast iron by being ductile rather than brittle, and by being malleable; it differs from malleable cast iron by being malleable without treatment subsequent to being cast; and from wrought iron chiefly by the process of manufacture, rather than by any great difference in physical properties.

Steel differs in chemical composition from pig iron, cast iron, and malleable cast iron chiefly by having a much lower percentage of carbon, but also by the smaller amounts of manganese, silicon, and phosphorus present. Low carbon steel and wrought iron differ very little in chemical composition, but with wrought iron the iron itself contains a smaller percentage of impurities for the reason that a part of the impurities are in the slag which is mechanically mixed with the iron.

**Effect of Composition on Properties.** — The element which has the most pronounced effect on the physical properties of steel is carbon. The amount of carbon present in steel may vary from almost 0 to about $1\frac{1}{2}$ per cent. Increasing the amount of carbon, increases the strength, hardness, and brittleness of steel but decreases the ductility. Steel may be classified according to carbon content approximately as follows:

| | *Carbon Content, Per cent* |
|---|---|
| Soft, mild, or low carbon steel.............. | Up to .30 |
| Medium, or medium carbon steel........... | .30 to .60 |
| Hard or high-carbon steel.................. | .60 to 1.50 |

There is no distinct line of demarkation between the various grades so these limits are subject to considerable variation.

Silicon, in the amounts usually found in steel, has little effect on its properties, but when the amount present is as high as 0.3 or 0.4 per cent it increases the strength without a sacrifice in ductility.

Sulphur has little effect on the strength or ductility of steel, but it makes steel brittle and liable to crack when worked at red heat. This is called *red shortness.* The maximum amount of sulphur permitted by specifications for structural steel is about 0.05 per cent.

Phosphorus causes steel to be brittle at ordinary temperatures, or *cold short,* and is therefore very objectionable. The maximum amount of phosphorus permitted by specifications for structural steel is about 0.06 per cent.

Manganese in amounts ordinarily present is beneficial to steel but its action is too complex to consider here.

**Effect of Mechanical Working.** — The hammering, pressing, and rolling of steel while hot tend to eliminate flaws, and if the working is continued while the metal is cooling past a certain critical temperature, the steel will be fine grained, due o the breaking up of the crystals and to not permitting them to form again.

The cold-working of steel increases the strength and elastic limit but decreases the ductility.

**Effect of Heat Treatment.** — Heating, annealing, and sudden cooling have very marked effects on the strength, ductility, and grain size of steel, but this subject is too complex for consideration here.

**Processes of Manufacture.** — The principal processes used in manufacturing steel are: The cementation process, and the crucible process, which produce steel by adding carbon to wrought iron; and the Bessemer process, and open-hearth process, which produce steel by purifying pig iron. Only the last two processes are used in making structural steel; therefore only these processes will be considered here. The open-hearth process is rapidly replacing the Bessemer process.

## Bessemer Process

The acid and the basic Bessemer processes are used in the manufacture of steel. The Acid process will be considered first.

**Plant.** — In the acid Bessemer process for making steel, molten pig iron is charged into a vessel called a converter, constructed as shown diagrammatically in Fig. 3*a*. This converter consists of a steel shell with a lining composed chiefly of silica and provided with tuyeres in the bottom, through which air may be forced. The converter is mounted on

a horizontal axis on which it can be rotated. The capacity of a converter is about 15 tons of pig iron.

**Operation.** — While being charged with molten pig iron, the converter is tipped as shown in Fig. 3*b*. The blast is turned on and the converter is rotated to a vertical position as shown in Fig. 3*a*. The pressure of the blast varies from 10 to 25 lb. per sq. in. The blow is continued for about

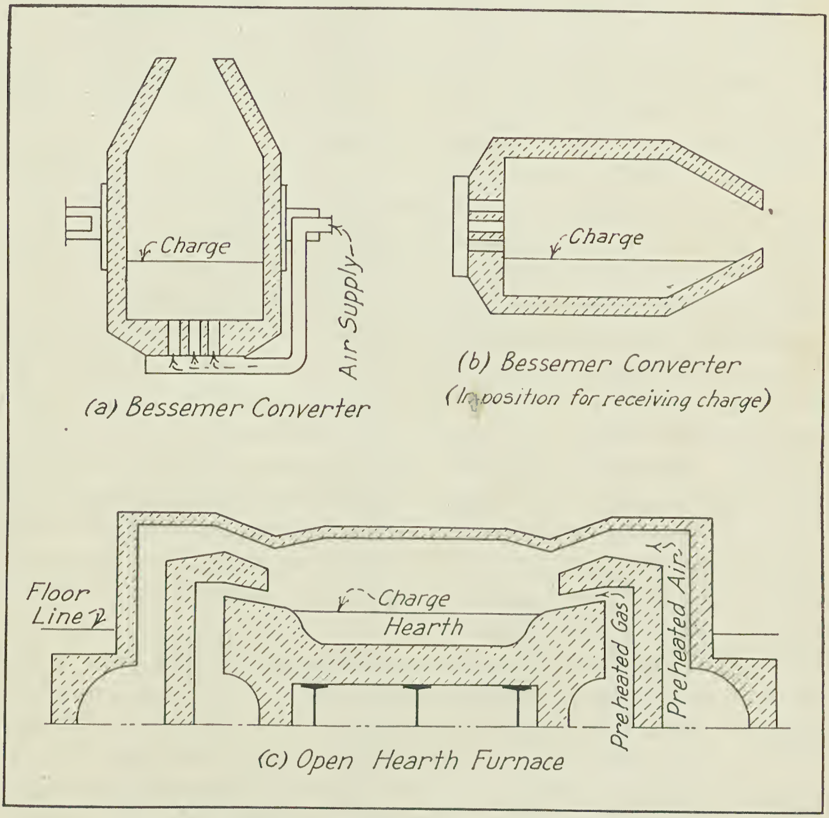



Fig. 3. Bessemer Converter and Open-hearth Furnace

10 minutes during which time a flame issues from the mouth of the converter. This flame is caused by the burning of the gases given off during the process. The operator judges from the appearance of the flame when the process is complete and pours the steel into a ladle by tipping the converter. From the ladle the steel is poured into ingot molds to form ingots.

**Removal of Impurities.** — The oxygen in the air blast combines with the silicon, manganese, and carbon in the pig iron forming the oxides $SiO_2$; $MnO$; and $CO$. The oxides of silicon and manganese form a slag

which separates from the iron, and the carbon monoxide, being a gas, passes out through the open end of the converter where it combines with oxygen from the air forming carbon dioxide ($CO_2$). The phosphorus and sulphur present in the pig iron are not removed by this process and the pig iron used must not contain large enough amounts of these materials to be objectionable in the steel. Since all of the phosphorus which is present in the ore charged into the blast furnace joins the pig iron it is evident that the only ores which can be used for acid Bessemer steel are those which do not contain enough phosphorus to injure the steel. Such ores are not plentiful in this country so are expensive and hence place a limit on the use of the acid Bessemer process.

**Sources of Heat.** — The melting point of the purified iron is higher than that of the pig iron, so if no heat were generated in the process the iron would not remain in a molten state. The heat required for the process is furnished primarily by the oxidation of the silicon but the oxidation of the carbon and the manganese furnish some heat.

**Recarburizing.** — During the process all of the carbon is removed from the pig iron and some iron oxide is formed. The amount of carbon desired in the steel is introduced by adding a *recarburizer* to the molten metal while it is still in the converter, or after it has been poured out into the ladle. The recarburizer has other functions to perform: The deoxidation of the steel, the introduction of elements such as manganese to improve the quality of the steel, and the removal of the small amount of carbon monoxide gas which tends to remain in the steel and cause blow holes. The material used as a recarburizer is a special pig iron which is high in manganese and carbon.

**The Basic Process.** — The process which has just been described is called the acid process because the slag formed is acid in character and requires a converter lining which is also acid in character to prevent chemical action between the lining and the slag. Phosphorus can be removed by the basic process where lime is charged into the converter to produce a slag which is basic in character. The phosphorus is the chief source of heat in the basic process, and ores, in order to be suitable for this process, must be high in phosphorus. The basic process is not used in this country, largely because of the lack of suitable ores.

**Advantages and Disadvantages.** — The chief advantages of the Bessemer process are its rapidity, the simplicity of the plant, and saving in fuel. The disadvantages are the lack of suitable ores and the variability of the product, the process depending largely on the skill of the operator in judging the time required for the reactions by the appearance of flame issuing from the mouth of the converter. The use of Bessemer steel is rapidly declining in favor of open-hearth steel.

## Open-hearth Process

**Plant.** — The open-hearth process for manufacturing steel is performed in an open-hearth furnace as shown diagrammatically in Fig. 3*c*. There are two open-hearth processes, the acid and the basic. The basic process will be considered first.

**The Basic Process.** — The furnace consists essentially of a hearth in the central portion and two openings, called ports, at each end. The hearth is lined with calcined magnesite with anhydrous tar as a binder. Under the action of heat the tar burns to coke and becomes hard and firm. The capacity of the furnaces in use varies from 50 to 100 tons.

**Operation.** — In charging the furnace, pig iron, steel scrap, iron ore and limestone are placed on the hearth through doors on one side of the furnace. The furnace is heated by introducing preheated gas through one port at one end of the furnace and preheated air through the other port at the same end. The gas and air ignite at the ports. The exhaust gases are drawn through both of the ports at the other end by natural draft. These gases pass through regenerators filled with checker brick and heat these brick to a high temperature. In about 20 minutes, valves are turned so that the direction of flow of the gases is reversed. The gas and air are preheated by passing through the regenerators which were heated by the exhaust gases. Regenerators are provided at each end of the furnace so that one set is always being heated by the exhaust gases while the other is heating the incoming gas and air. The direction of flow is changed at intervals of 15 or 20 minutes. The regenerators make it possible to heat the furnace to a temperature high enough to melt the charge in 4 or 5 hours. The process requires from 6 to 12 hours to accomplish the removal of the impurities. Then the furnace is tapped through a tap hole and the molten steel is run into ladles.



**Removal of Impurities.** — The oxygen in the iron ore of the charge is the oxidizing agent which combines with the silicon, manganese, and phosphorus present in the charge forming the corresponding oxides which, with the lime of the charge, form the slag. The carbon present in the materials charged into the furnace is oxidized by the oxygen of the iron ore forming carbon dioxide gas which leaves the furnace with the other exhaust gases. The elimination of sulphur is quite uncertain.

**Sources of Heat.** — Some heat is supplied by the oxidation of the impurities but most of the heat is obtained from the combustion of the fuel which may be gas, fuel oil, or powdered coal.

**Recarburizing.** — The process is always continued until the amount of carbon present is less than that desired in the finished steel. The ad-

ditional carbon is supplied by adding ferro-manganese with coal, charcoal, or coke to the metal in ladle.

**The Acid Process.** — The process which has just been described is the basic process because the slag formed is basic in character and requires a basic lining for the hearth to prevent any chemical action between the slag and the lining. Phosphorus can be removed by the basic process but not by the acid process; and since all of the ores in this country contain phosphorus in objectionable amounts the acid process has very little use.

The acid process differs from the basic in the following respects: The lining of the hearth is acid in character instead of basic, the charge must be low in phosphorus, and the recarburizing may be done in the furnace instead of in the ladle as in the basic process.

**Advantages and Disadvantages.** — The chief advantage of the open-hearth process over the Bessemer process is the possibility of better control due to the slowness of the process. The chief disadvantages are the time required and the additional fuel necessary, the heat in the Bessemer process being supplied entirely by the oxidation of the impurities in the charge. Open-hearth steel is generally specified for structural purposes. The use of Bessemer steel is rapidly declining.

## ARTICLE 9. NON-FERROUS METALS AND ALLOYS

### Copper

**Ores.** — Copper is found in the native or pure state and in a great variety of ores of which the sulphides are the most common.

**Extraction.** — The stages in the extraction of copper from sulphide ores are:

1. *Concentrating* the lean ores by crushing, passing through stamp mills, and then through *jigs* where the ore is shaken so that the heavier material containing the copper falls to the bottom and the lighter material rises to the top. This lighter material is washed away by a stream of water, leaving the concentrate containing a high percentage of copper, with considerable iron present as an impurity.

2. *Roasting* the sulphide ore by heating in an oxidizing atmosphere where a part of the iron sulphide ore is converted into the oxide by the burning out of the sulphide. The temperature is not high enough to melt the ore. The roasted ore contains chiefly copper sulphide, iron oxide, and siliceous gangue, although some copper oxide may be present.

3. *Smelting* in a blast furnace with coke as a fuel or in a reverberatory furnace similar to that used in the manufacture of wrought iron as described in Article 7. Copper sulphide and iron sulphide settle to the

bottom forming a *matte;* and the slag, containing the *gangue* or earthy materials and iron oxide, forms on top where it may be drawn off.

4. *Converting* the molten matte, containing the sulphides of copper and iron, in a converter similar to that used in the manufacture of Bessemer steel. Air is blown through the molten matte and provides oxygen which combines with the iron sulphide forming a slag of iron oxide on top of the remaining copper sulphide. By continuing the process, the sulphur is burned out of the sulphides and forms sulphur dioxide which passes off as a gas and leaving an impure form of copper known as *blister copper.*

5. *Refining* the blister copper either in a reverberatory furnace or electrolytically. In *furnace-* or *fire-refining* the blister copper is melted in a reverberatory furnace; the slag which is formed is skimmed off; air is blown over the molten bath and oxidizes the impurities which either pass off as gas or form slag on top of the molten metal. Some of the copper is oxidized and must be reduced by adding charcoal and green branches of trees to the bath. Steam formed by the water in the green branches agitates the bath and the carbon from the charcoal and the charred branches combines with the oxygen of the copper oxide forming carbon monoxide which passes off as a gas thus leaving fairly pure copper, which is cast into ingots.

In the *electrolytic process* anodes of blister copper or fire-refined copper and cathodes of pure copper are placed in a copper sulphate bath. An electric current is passed through the bath and causes pure copper to be transferred from the blister copper anode to the pure copper cathode. The impurities, which often include the precious metals, are not soluble in copper sulphate and being of higher specific gravity fall to the bottom of the bath and are removed.

Fire-refined copper is not as pure as that obtained by the electrolytic process. The former is used for wires, tubes, and plates and for making brasses and bronzes. The latter is used primarily for electrical purposes which require the purer form.

**Properties and Uses.** — The most important properties of copper are its electrical conductivity and its resistance to corrosion. Its strength and ductility are greatly affected by the mechanical and heat treatment it receives. If heated to a red heat and cooled slowly it is brittle, but if cooled quickly it is malleable and ductile. It may be cast and welded and may be rolled or drawn when hot or cold. Cold-working increases its strength but decreases its ductility. When exposed to moist air, as when used for a roofing material, a thin coating of the green basic carbonate is formed. This protects the copper so that no further treatment is required.

Copper is used primarily for electrical purposes but it is also used extensively as a constituent of brasses and bronzes and for sheet metal roofing and shingles, gutters, rain conductors, flashing and tubes. Copper wire is formed by drawing through dies. If it is cold-drawn, it produces what is called *hard-drawn wire* which is springy.

## Zinc

The ores of zinc are the sulphide ($ZnS$) called *sphalerite, black jack* or *zinc blende;* the carbonate ($ZnCO_3$) called *smithsonite* or *zinc spar;* the silicates ($Zn_2\ SiO_4\ H_2O$) called *calamine* and ($Zn_2\ SiO_4$) *willimite;* and *franklinite,* which is composed of the oxides of zinc, manganese, and iron. The most common source of zinc is zinc blende.

**Extraction.** — The stages in the extraction of zinc from its ores are:

1. *Roasting* the ore to drive off the sulphur from sulphides and the carbon dioxide from the carbonates to form zinc oxide.

2. *Mixing* the oxide with nearly an equal amount of finely ground coal or coke and placing in fire-clay retorts.

3. *Heating* retorts to a white heat so that the coal or coke will form carbon monoxide which will combine with the oxygen of the zinc oxide forming carbon dioxide and zinc vapor.

4. *Condensing* the zinc vapor at a temperature above the melting point of zinc to form molten zinc which is poured into molds and allowed to cool forming *zinc spelter* which is the form commonly used. If the temperature at which the condensation is carried on is too low, *zinc dust* is formed. This cannot be melted to form a solid mass and has a limited use in the powdered form.

**Properties and Uses.** — Zinc has a fairly high resistance to corrosion. For this reason it is used as a roofing material in the form of sheet zinc. Exposure to the weather causes dull gray zinc carbonate to form on the surface. This protects the remainder of the metal.

If zinc is cooled suddenly from the molten state it is malleable but if cooled slowly it is hard and brittle. Commercial zinc is quite brittle but if heated to about 250 deg. fahr. it becomes malleable and ductile. It may then be drawn into wire or rolled into sheets which are ductile and malleable when cool. Molten zinc shrinks very little in solidifying and casts well.

Zinc is extensively used as a protective coating for steel in the galvanizing and sherardizing processes. It is also used as one of the constituents in brass, nickel silver, and other alloys and in making electric batteries.

## Lead

**Ores.** — The only important ore of lead is *galena* which is the sulphide (PbS) mixed with gangue.

**Extraction.** — The stages in the extraction of lead from its ores are:

1. *Roasting* by charging crushed ore into a reverberatory furnace where it is heated at a low temperature in an oxidizing atmosphere. Part of the sulphur in the sulphide is oxidized forming lead oxide and sulphur dioxide gas and some lead sulphate is formed, thus:

$$PbS + 3O = PbO + SO_2$$
$$PbS + 4O = PbSO_4$$

2. *Smelting* the lead oxide, the lead sulphate, and the remaining lead sulphide in a blast furnace with limestone, coke and some other materials to form lead and sulphur dioxide, thus:

$$PbS + 2PbO = 3Pb + SO_2$$
$$PbS + PbSO_4 = 2Pb + 2SO_2$$

The molten lead thus formed is drawn off and cast into ingots. This lead must usually be purified before it is ready for the market.

**Properties and Uses.** — The important physical properties of lead are its resistance to corrosion, its plasticity, and its malleability.

Lead sheets are used to considerable extent for water-tight pans under the floors of shower baths and in similar positions. They are used to a limited extent for roofing, particularly for curved or irregular surfaces to which lead can be easily fitted by stretching and working. Lead has a high coefficient of expansion and is difficult to hold in place, particularly on pitched roofs.

A roofing known as *hard lead* is composed of lead and antimony. It is stronger and has a lower coefficient of expansion than ordinary lead and can be used on any slope.

Lead pipes are used in plumbing but not to the extent they were in former years. The pipe is formed by forcing the metal through dies by means of hydraulic presses. The term *plumber* is derived from the Latin word *plumbum* meaning lead.

*Solder* is an alloy of lead and tin.

## Aluminum

**Ores.** — Aluminum occurs very abundantly in nature in combination with oxygen, sodium, fluorine, and silicon. The chief source of aluminum is *bauxite* which is hydrated oxide of aluminum and iron with some silicon. The most extensive occurrance of aluminum is as the oxide alumina

($Al_2O_3$) which is the principle constituent of clay. No process has yet been devised to obtain aluminum from clay in commercial quantities.

**Extraction.** — The stages in the extraction of aluminum from bauxite are:

1. *Roasting* bauxite to drive off the water.

2. *Grinding* roasted bauxite and heating under pressure with a solution of sodium hydrate forming sodium aluminate.

3. *Precipitating* aluminum hydroxide by heating sodium aluminate solution with aluminum hydroxide or with carbon dioxide.

4. *Separating* aluminum hydroxide by filtering and dehydrating by heating to form alumina ($Al_2O_3$).

5. *Extracting* aluminum from alumina by the electrolytic decomposition of alumina in a molten bath of cryolite which is the fluoride of alumina and sodium.

In the last named process the containing vessel is lined with carbon in the form of graphite or coke which forms the cathode. Carbon rods suspended in the bath form the anode to which the oxygen goes. The cryolite is melted by the heat generated by the passage of the electric current across a gap which exists between the anodes and the cathodes. When the cryolite bath becomes molten, alumina is thrown on the bath and as it melts it is broken up into molten aluminum, which settles on the cathode, and oxygen which goes to the anode with which it combines, forming carbon monoxide which escapes as a gas. The molten aluminum is tapped off as it accumulates. The heat for the process is supplied by the electric current.

**Properties and Uses.** — Aluminum has a low electrical resistance which makes it valuable for transmission lines and other electrical uses. It is a good heat conductor and is non-corrosive so is useful in either the cast or spun form for cooking utensils. It has many special uses on account of its lightness; its weight is only about one-third that of iron but it is usually alloyed with other metals which increase its strength. It is very malleable, quite ductile, and is strong in proportion to its weight. It may be drawn into wire and rolled into very thin sheets and shaped in many other ways.

## Tin

**Ores.** — The principal source of tin is the black oxide ($SnO_2$), known as *cassiterite* or *tinstone.* Tin is the only important metal not found in the United States.

**Extraction.** — The stages in the extraction of tin from its ores are:

1. *Concentrating* the ore by stamping and washing to remove the lighter materials.

2. *Roasting* in a reverberatory furnace to oxidize the sulphur and arsenic which exist as impurities. These oxides pass off as gases.

3. *Smelting* in reverberatory or blast furnaces. The oxygen of the tin oxide combines with carbon to form carbon dioxide, the carbon being mixed directly with the ore in the furnace, or the oxygen combines with carbon monoxide derived from the partial combustion of coal used as a source of heat. The molten tin accumulates and is drawn off. This crude or raw tin contains copper, iron, arsenic, sulphur. and other impurities.

4. *Refining* by liquation and boiling. The ingots of crude tin are placed in a reverberatory furnace and as the temperature is gradually increased the tin melts and is removed leaving the unfused impurities. The molten tin thus obtained is still further purified by boiling while bundles of green twigs are held submerged in the molten tin. The steam given off by the green twigs develops violent boiling which causes the impurities to become oxidized by coming in contact with the air. These oxides form a scum on the surface. This scum is removed and the tin is cast into ingots. Some of the impurities are heavier than the tin and do not pass into the scum but settle toward the bottom. For this reason the tin which comes from the top of the vessel is purer than that which comes from the bottom. The former is called *refined tin* and the latter *common tin.* The common tin is often liquefied and boiled again.

**Properties and Uses.** — Tin is very malleable and may be rolled into very thin sheets which are called *tinfoil.* It is very resistant to corrosion. Its principal use is in coating sheet iron or steel to form *tin plate* for use as a roof covering. Tin plate used for roofing does not have a coating of pure tin but of an alloy of 25 per cent tin and 75 per cent lead. This is known as *terne plate* and is much less expensive than *bright* tin plate which is coated with pure tin.

Tin is used in making bronzes and other alloys.

## Alloys

**The Brasses.** — The brasses are alloys of copper and zinc. The most useful brass alloys range in composition from 60 per cent copper and 40 per cent zinc to 90 per cent copper and 10 per cent zinc. Standard brass contains 2 parts of copper to 1 part of zinc and is the most commonly used of all the brasses. Those carrying a large amount of copper are copper red in color and those with a small amount of copper are a silvery white.

Brass may be shaped by casting, hammering, stamping, rolling into sheets, or drawing into wire or tubes.

Muntz metal contains 60 per cent copper and 40 per cent zinc.

The addition of even small amounts of tin to brass greatly increases the resistance to corrosion.

**The Bronzes.** — The bronzes are alloys of copper and tin ranging in composition from 95 per cent copper and 5 per cent tin to 75 per cent copper and 25 per cent tin. The chief effect of tin on copper is to increase its hardness.

Gun metal contains 90 per cent copper and 10 per cent tin. It is the strongest of the bronzes. Bell metal contains 80 per cent copper and 20 per cent tin. It is hard and is used for making bells. Speculum metal contains 2 parts copper and 1 part tin. It is a hard white metal which will take a polish and is used for making mirrors.

Phosphor bronze is a copper-tin alloy to which a small amount of phosphorus has been added as a deoxidizer to eliminate copper oxide. This results in a very marked improvement in the strength and quality of the bronze. It is highly resistant to corrosion.

Manganese bronze is really a brass for it contains a large amount of zinc and little or no tin. The manganese acts as a dioxidizer and does not appear in the resultant alloy as it has been oxidized and removed in the flux. The addition of manganese greatly improves the strength of the alloy. Manganese bronze is an excellent material for castings and is very resistant to corrosion.

## ARTICLE 10. TIMBER

**Classification of Trees.** — Timber for construction purposes is furnished by two classes of trees: the *needle-leaved conifers* such as the pine, fir, and spruce, and the *broad-leaved trees* such as the maple, oak, and poplar. The woods furnished by the conifers are commonly classed as *softwoods* and those furnished by the broad-leaved trees as *hardwoods* although poplar is as soft as pine and some of the softwoods are as hard as the harder hardwoods.

**Manner of Growth.** — The conifers and broad-leaved trees grow by adding each year a layer of wood to all parts of the tree. This layer shows in the cross-section as a new ring surrounding the old wood and under the bark. The rings thus formed are known as *annual rings.*

**Structures.** — The cross-section of a tree consists of the annual rings surrounding the *pith* at the center of the section and surrounded by the *bark.* The pith varies in diameter from $\frac{1}{20}$ of an inch in some kinds of wood to nearly $\frac{1}{4}$ of an inch in others.

The annual rings near the outside of the section form the *sapwood* and are lighter in color than those near the center which form the *heartwood.*

The sapwood is active and assists in the life processes of the tree by storing up starch and conducting sap. The heartwood is dead, its only function being to contribute to the strength of the tree.

Each annual ring is made up of an inner portion which is relatively soft and light-colored and an outer portion which is harder and darker in color. The inner portion is formed early in the growing season and is known as *spring wood* whereas the outer portion is formed later and is known as *summer wood.* In some woods there is a distinct line of demarkation between the spring wood and summer wood but in others the spring wood merges gradually into the summer wood.

Wood is composed primarily of long thin cells or fibers closed at the ends and with their length parallel to the length of the tree. In addition to these cells there are other groups of cells running radially and forming the *medullary* or *pith rays.* In the conifers the sap is conducted through the cells by passing through the walls, but in the hardwoods the sap passes through cells with open ends set one above another forming continuous tubes called *pores* or *vessels.* In some of the conifers, such as pine and spruce, there are intercellular passages, called *resin ducts,* which store and conduct resin. They occur horizontally, in the medullary rays, as well as vertically. The functions of the medullary rays are to store food and to provide for the passage of sap between the bark and the sapwood.

Though similar in many respects, the conifers and broad-leaved trees are very different in the structure of their wood. The structure of the wood of the conifers is simple and regular with a uniform type of cell or fiber. The wood of the broad-leaved trees is quite complex in structure with many different types of cells or fibers and a very irregular arrangement.

**Methods of Grading.** — The methods used in grading lumber are explained in Circular 64 of the United States Department of Agriculture entitled, "How Lumber is Graded," by H. S. Betts, from which the following quotations are made:

The boards cut in a sawmill from logs of various kinds vary widely in quality. Some boards are very knotty, others have a few knots, and still others are clear. Some contain checks or splits and others have bark on the edges or are somewhat decayed in places. The clear boards are more valuable for most purposes than those with knots, so it becomes necessary to separate the lumber as it comes from the mill into classes or grades. The lumber in these grades varies in quality from practically clear boards in the highest grade to lumber in the lowest grade containing so many knots, checks, and other defects that it is unfit for anything except perhaps temporary construction or for cutting up to obtain small, clear pieces, the defective parts being discarded.

The use to which lumber is to be put determines the number, size, and position of the defects it may contain and still be satisfactory. In siding, for example, a reasonable number of knots on the edges which are covered when the siding is in place may evidently be allowed. In flooring some knots and other defects on the under side are allowable, since they will not show when the flooring is in use. Sheathing and subflooring may have a considerable number of defects, since both kinds of lumber are entirely covered by finishing material. Covered lumber, such as sheathing, should, of course, be free from decay, even if it does not show, as the decay is quite likely to spread rapidly. Door panels are an example of very high grade lumber that should be clear on both sides.

The location of defects in a piece of lumber determines the length and width of clear pieces that can be cut from it and the waste that will occur when the cuttings are made. Furniture requires comparatively short, wide pieces of clear lumber, while rails for porches and stairs require long, narrow, clear lengths. Lumber from which a large proportion of furniture stock should be cut might yield very little rail stock.

The condition of defects may also influence the grade of a piece of lumber. Tight knots in certain grades of siding or ceiling may be allowed, whereas loose knots likely to drop out would be objectionable.

The grading rules in general use at present with very few exceptions have to do only with defects and do not take into account the quality of the wood itself. That is, if two boards of the same species are clear or if they have similar defects, both boards are placed in the same grade regardless of the quality of the wood itself. As a matter of fact, the wood in one board may be dense, heavy, and strong and the wood in the other light and weak. For some purposes, such as siding, ceiling, or finish, it may not matter whether dense or light wood is used; but for other purposes, such as vehicle parts, structural timber, or flooring, where strength or hardness is a prime requisite, the wood must be dense to give satisfactory service.

**Classification According to Use.** — Lumber is commonly divided into four classes according to use: Hardwood factory lumber, softwood factory lumber, yard lumber, and structural timber. *Hardwood* and *softwood factory lumber* are used by factories and mills in making furniture, implements, vehicles, and such products as window sash, doors, and millwork of various kinds used in building construction. *Yard lumber* includes the small-sized lumber under 5 in. in thickness usually carried by lumber yards and used chiefly in building construction. *Structural timber* is large-sized lumber 5 in. or over in width and thickness. Such timbers are largely used in structures where strength is an important factor. On account of the difference in the requirements for lumber in each of these classes, each class must necessarily have its own grading rules.

**Size Classification.** — The American Lumber Standards for softwood lumber divide yard lumber and structural timber into the following classes according to size:

(*a*) **Strips.** Yard lumber less than 2 in. thick and under 8 in. wide.

(*b*) **Boards.** Yard lumber less than 2 in. thick, 8 in. or over in width.

(*c*) **Dimension.** All yard lumber except boards, strips, and timbers; that is, yard lumber 2 in. and under 5 in. thick, and any width.

(1) *Planks:* Yard lumber 2 in. and under 4 in. thick and 8 in. and over wide.

(2) *Scantlings:* Yard lumber 2 in. and under 5 in. thick and under 8 in. wide.

(3) *Heavy joists:* Yard lumber 4 in. thick and 8 in. or over wide.

(*d*) **Timbers.** Lumber 5 in. or larger in least dimension.

**Manufacturing Classification.** — Manufactured softwood lumber is classified by the American Lumber Standards according to the nature of the work done on it into:

(*a*) **Rough lumber.** Undressed as it comes from the saw.

(*b*) **Surfaced lumber.** Lumber that is dressed by running through the planer. It may be surfaced on one side (S1S), two sides (S2S), one edge (S1E), two edges (S2E), or a combination of sides and edges, (S1S1E), (S2S1E), (S1S2E) or (S4S).

(*c*) **Worked lumber.** Lumber which has been run through a matching machine, sticker, or molder. Worked lumber may be matched, shiplapped, or patterned.

(1) *Matched lumber:* Lumber that is edge dressed and shaped to make a close tongue-and-grooved joint at the edges or ends when laid edge to edge or end to end.

(2) *Shiplapped lumber:* Lumber that is edge dressed to make a close rabbetted or lapped joint.

(3) *Patterned lumber:* Worked lumber that is shaped to a patterned or molded form.

**Lumber Grades.** — The grades for hardwood lumber as adopted by the National Hardwood Lumber Association are: Firsts, Seconds, Selects, No. 1 Common, No. 2 Common, and No. 3 Common. Firsts and Seconds are usually included in one grade designated F A S.

The basic grade classification for softwood yard lumber according to the American Lumber Standards is given on p. 50. These standards do not replace the grading rules of the various lumber manufacturers associations which are designed to suit the properties of the various species of softwood lumber.

Basic Grade Classifications for Softwood Yard Lumber

| | | | |
|---|---|---|---|
| Total products of a typical log arranged in series according to quality as determined by appearance. | Select<br>Lumber of good appearance and finishing qualities. | Suitable for natural finishes. | Grade A — Practically free from defects. |
| | | | Grade B — Allows a few small defects or blemishes. |
| | | Suitable for paint finishes. | Grade C — Allows a limited number of small defects or blemishes that can be covered with paint. |
| | | | Grade D — Allows any number of defects or blemishes which do not detract from a finish appearance, especially when painted. |
| | Common<br>Lumber containing defects or blemishes which detract from a finish appearance but which is suitable for general utility and construction purposes. | Lumber suitable for use without waste. | No. 1 common — Sound and tight knotted stock. Size of defects and blemishes limited. May be considered water-tight lumber. |
| | | | No. 2 common — Allows large and coarse defects. May be considered grain-tight lumber. |
| | | Lumber permitting waste. | No. 3 common — Allows larger and coarser defects than No. 2 and occasional knot holes. |
| | | | No. 4 common — Low quality lumber admitting the coarsest defects, such as decay and holes. |
| | | | No. 5 common — Must hold together under ordinary handling. |

The defects and blemishes used in grading softwood yard lumber are given in the paragraph on *Defects in Lumber.*

Structural timber is divided into three grades: (*a*) Dense select, (*b*) select, and (*c*) common. In the first two grades selection is made partly on the basis of the rate of growth and the density.

**Defects in Lumber.** — In the grading of lumber it is necessary to classify and define the defects and blemishes which occur in the lumber. The commonly recognized defects and blemishes occurring in softwood yard lumber as given by the American Lumber Standards are:

A *bark pocket* is a patch of bark partially or wholly inclosed in the wood. In size it is classified the same as pitch pockets.

"*Bird's-eye*" is a small central spot with the wood fibers arranged around it in the form of an ellipse, so as to give the appearance of an eye. "Bird's-eye," unless unsound or hollow, shall not be considered a defect.

A *check* is a lengthwise separation of the wood, which occurs usually across the rings of annual growth.

A *cross break* is a separation of the wood cells across the grain, such as may be due to tension resulting from unequal shrinkage or mechanical stresses.

*Cross-grained wood* is that in which the cells or fibers do not run parallel with the axis, or sides of a piece.

*Decay* is a disintegration of the wood substance due to the action of wood-destroying fungi. The words *dote* and *rot* mean the same as decay.

A *gum spot* or *streak* is an accumulation of gumlike substance occurring as a small patch or streak in a piece. It may occur in conjunction with a bird peck, or other injury to the growing wood. In size they are classified the same as pitch pockets or pitch streaks.

*Imperfect manufacture* includes all defects or blemishes which are produced in manufacturing, such as chipped grain, loosened grain, raised grain, torn grain, skips in dressing, hit and miss, variation in sawing, miscut lumber, machine burn, machine gouge, mismatching, and insufficient tongue or groove.

A *knot* is a branch or limb embedded in the tree which has been cut through in the process of lumber manufacture. Knots are classified according to size, form, quality, and occurrence. The average of the maximum and minimum diameters shall be used in measuring the size of knots, unless otherwise stated.

*Pitch* is a poorly defined accumulation of resin in the wood cells in a more or less irregular patch.

A *pitch pocket* is a well-defined opening between rings of annual growth, usually containing, or which has contained, more or less pitch, either solid or liquid. Bark also may be present in the pocket.

A *pitch seam* is a shake or check which is filled with pitch.

A *pitch streak* is a well-defined accumulation of pitch in a more or less regular streak.

*Pith* is the small soft core occurring in the structural center of a log. The wood immediately surrounding the pith often contains small checks, shakes, or numerous pin knots, and is discolored; any such combination of defects and blemishes is known as *heart center.*

A *pith fleck* is a narrow streak resembling pith, usually brownish, up to several inches in length, on the surface of a piece resulting from burrowing of larvae in the growing tissue of the tree.

A *shake* is a lengthwise separation of the wood, which occurs usually between and parallel to the rings of annual growth.

A *split* is a lengthwise separation of the wood, due to the tearing apart of the wood cells.

*Stain* is a discoloration, occurring on or in lumber, of any color other than the natural color of the piece on which it appears.

*Wane* is bark, or the lack of wood or bark, for any cause, on the edge or corner of a piece.

*Warp* is any variation from a true or plane surface. It includes bow, crook, cup, or any combination thereof.

The standards include several subdivisions under each of the defects and blemishes which have been quoted.

In the grading of the hardwoods the defects which have been adopted as standard differ somewhat from those recognized for the softwoods. Each of the following counts as a standard defect, the grade of a piece being determined largely by the number of standard defects it contains:

1. One knot $1\frac{1}{4}$ in. in diameter.
2. Two knots $\frac{5}{8}$ in. in diameter or their equivalent. Knots of $2\frac{1}{2}$ in. in diameter count as 2 standard defects; those $2\frac{3}{4}$ in. in diameter as 3 standard defects, and those 5 in. in diameter as 4 standard defects.
3. One split diverging from parallel to the edges not more than 1 in. to a foot in length and not longer in inches than the surface in feet.
4. Wane not more than 1 in. wide and extending not more than one-sixth the length of the piece or its equivalent at one or both ends. (Wane is bevel or bark on the edge of a board and is due to incomplete edging of a board wider at one end than at the other.)
5. Worm, grub, knot, and rafting pin holes which do not exceed in damage or extent that of one knot $1\frac{1}{4}$ in. in diameter.
6. Equivalent defects. Heart center or pith and any other imperfections not listed as standard defects which do not damage the piece more than is done by allowable standard defects, are considered standard defects.

**Plain- and Quarter-sawed Lumber.** — Boards which are sawed from the logs with their face tangent to the annual rings are called *plain-sawed* or *flat-sawed* while those which are sawed in a perpendicular direction are called *quarter-sawed* or *edge-grain.*

Boards in which the annual rings or grain are neither tangent nor perpendicular to the sides are classed as quarter-sawed if the grain makes an angle greater than 45 deg. with the side of the board. If this angle is less than 45 deg. the boards are classed as plain-sawed. Quarter-sawed lumber shrinks and warps less than plain-sawed lumber and wears better. The exposed grains of wood are different when quarter-sawed than when plain-sawed. In some cases more attractive effects are secured in quarter-sawed boards but in others the plain-sawed boards have the advantage. Quarter-sawed lumber is less plentiful than plain-sawed lumber and is more expensive.

**Size Standards.** — On account of shrinkage and the waste due to sawing and dressing softwood yard lumber designated as 1 in. thick is required to be $\frac{25}{32}$ in. thick after surfacing and 2-in. material is required to be $1\frac{5}{8}$ in. thick. Corresponding allowances varying from $\frac{3}{8}$ in. to $\frac{3}{4}$ in. are made in the widths; the amount in each case depends upon the width of the material, a smaller allowance being made for a piece whose nominal width is 4 in. than for one whose nominal width is 12 in. Rough lumber is larger than surfaced lumber by the amount necessary for surfacing.

Hardwood lumber is cut oversize so that it will be full size when dry. When surfaced on one side the thickness is $\frac{1}{8}$ in. less than the rough size and when surfaced on two sides it is $\frac{3}{16}$ in. less than the rough size.

The standard lengths for softwood lumber vary by 2-ft. increments from 4 ft. up, the most common lengths being 12, 14, and 16 ft. A few

odd lengths as 9, 11, 15, and 17 ft. are considered as standard for specified sizes. The standard lengths of hardwood lumber vary by increments of 1 ft. from 4 to 16 ft., but not over 15 per cent of the odd lengths is permitted by grading rules.

**Units of Measure.** — The principal unit of measure for lumber is the *board-foot.* It is a board 1 ft. sq. and 1 in. thick or its equivalent in volume. For example, a 1 × 12-in. has 1 board foot per foot of length, while a 2 × 4-in. has $\frac{2}{3}$ of a board foot per foot of length. Nominal sizes are used and not actual sizes. Lumber of which the nominal thickness is less than 1 in. is considered as 1 in. thick.

This method of measurement is called board measure and is abbreviated b.m. The common unit is 1000 board feet, designated as M. For example, if a lot of lumber contains 25,000 board feet it is designated as 25 M.b.m.

Moldings are measured by the lineal foot and lath and shingles by the number of pieces of a specified size.

**Seasoning.** — The *seasoning* of timber is simply the natural drying out due to exposure to the air. This drying out process may be hastened by subjecting the timber to high temperatures in a kiln. This is called *kiln drying.* The principal effects of seasoning and kiln drying on timber are: Reduction in weight; decrease in the amount of shrinking, checking, and warping after the timber is placed; increase in resistance to decay; and increase in strength.

**Decay.** — The decay of timber is caused by low forms of plant life called *fungi* which feed on the cell walls and destroy them. In order to develop, these fungi require warmth, air, and moisture. At low temperatures the fungi are dormant but are not destroyed. However they are killed by very high temperatures. Timber which remains under water will last indefinitely because the air which fungi require is excluded. Pieces of timber have lasted for thousands of years under water. If moisture is not present, wood will not decay. Even in the case of *dry rot* moisture is present. It may be caused by sealing the surface of a timber with paint or embedding the timber in masonry in such a way that the moisture present in the timber cannot escape and is therefore available for the development of fungi.

**Wood Preservation.** — The proper seasoning of timber is the simplest way for preventing decay but when timber is used where moisture is present seasoning naturally loses its effectiveness. Under these conditions the best method for checking decay is to introduce some substances into the timber which will poison the fungi. The substances commonly used for this purpose are zinc chloride and creosote. Zinc chloride is made by dissolving zinc in hydrochloric acid. Creosote is obtained from

the distillation of coal tar. Zinc chloride is soluble in water and is suitable for use only where it will not be leached out by the action of water and when the method of applying it is such as to secure considerable penetration of the zinc chloride into the timber. Creosote does not suffer from these handicaps.

Creosote may be applied with a brush or spray but this method is not very effective for the coating is thin and it is difficult to fill all of the cracks. The advantage of this method is the low cost. Another simple method consists of dipping the timber in a tank of hot creosote. This method is more effective than brushing or spraying but only a slight penetration of the creosote into the wood is secured.

In the *open-tank process* the timber to be treated is first placed in a tank of hot creosote and then in a tank of cooler creosote. While the timber is in the first tank the air contained in the timber expands and some of it is forced out of the timber. When the timber is placed in the second tank the air contracts and draws the creosote into the wood, thus securing a deeper penetration than is obtained by dipping in hot creosote alone.

Various processes are used to secure a deeper penetration of the preservative into the timber by pressure. These processes require extensive equipment and are expensive but their use is justified where the most effective treatment is required as in the case of piling. These processes use cylinders as large as 8 ft. in diameter and 150 ft. long. The material to be treated is loaded on cars and run into a cylinder the ends of which are then closed by tight doors. In one process, the first step is to exhaust some of the air from the cylinder in order to draw the air and moisture from the timber. Creosote is then introduced into the tank and is forced into the cells of the wood by pressure. The treatment is completed by drawing off the creosote and removing the timber after the excess creosote has been permitted to drip off. This process leaves the cells, to the depth which the creosote has penetrated, full of creosote and is known as the *full-cell process.*

In another process the creosote is first forced into the timber by pressure and then the creosote which is in the cells is removed by creating a vacuum. Only the creosote in the cell walls remain. This is known as an *empty-cell process* and is therefore less expensive than the full-cell process.

When zinc chloride is used as a preservative the full-cell process is adopted.

**Kinds of Wood and Their Uses.** — The most common softwoods used in building construction are the white, soft, and yellow pines, Douglas fir, redwood, spruce, cedars, hemlocks and cypress.

The *white* or *soft pines* are slightly resinous, soft, easy to work, weather resistant and take paint well. They are used for doors, window frames and sash, and for interior finish with a paint or enamel finish. They are excellent woods for exterior finish but are too expensive for that use. On account of their softness they are not suitable for floors which are subjected to much use. Some of the soft pines are: Pondosa pine, California white pine, Idaho white pine, northern white pine, and sugar pine.

The *yellow* or *hard pines* are usually quite resinous, heavy, hard, and strong. They are harder to work than white pine and on account of the resin which they contain they are difficult to paint. They are used extensively for structural timbers and make an excellent flooring material. Many species of varying properties are on the market and different names are used for the same species. The more common are yellow pine, hard pine, long-leaf pine, short-leaf pine, southern pine and pitch pine. Long-leaf pine is superior in strength and other qualities to short-leaf pine.

*Douglas fir* is harder, more resinous, and more difficult to work than white pine but softer, less resinous, and easier to work than yellow pine. It takes paint well and is suitable for use as a structural material and for interior and exterior finish. Douglas fir is also known as Oregon fir and Oregon pine.

*Redwood* is a light, soft, durable wood which is easy to work and takes paint well. It is extensively used for interior and exterior finish, doors, sash and shingles.

*Spruce* resembles soft pine. It is light, soft, and contains a small amount of resin. Spruce is used for siding, interior and exterior finish and as a structural material.

*Western Red Cedar* is a light weight, soft, close-grained wood which takes paint well and is very durable. It is used extensively for shingles on account of its durability, and for interior and exterior finish and siding.

*Cypress* is a close, straight-grained, softwood which is very durable. On account of its oily sap, great care is required in painting. It is used for interior and exterior finish, siding, and for structural members.

*Hemlock* is a soft, rough, coarse, cross-grained, non-resinous wood which is difficult to work and is not used extensively in building construction. The use of West Coast hemlock for general construction purposes is increasing.

The most common hardwoods used in building construction are oak, maple, birch, beech, poplar, and gum. Some of these are suitable for structural purposes but they are not so used on account of their high cost.

*Oak* is a hard, heavy, strong, tough, durable, open-grained wood with a very attractive grain. It is extensively used in building construction for interior finish and for floors. It is usually finished by varnishing or waxing so as not to conceal its grain. There are many species of oak but they are usually divided into white oak and red oak.

*Maple* is a hard, close-grained, tough, strong, heavy wood which is difficult to work. It is extensively used for floors because of its excellent wearing qualities.

There are two classes of maples: the hard maple and the soft maple. Hard maple is obtained from the sugar maple and soft maple from the silver maple and the red maple. White maple is the sapwood from any species.

*Birch* is a strong, hard, close-grained wood with a fine texture. It is very attractive when finished in its natural color but since it takes stain so well it is often finished to imitate walnut, mahogany, and cherry. There are two species of birch: red birch and white or yellow birch. Birch is extensively used for interior finish, doors, and to a limited extent for floors. It is not durable if exposed.

*Beech* is a hard, tough, coarse-textured wood which is used to a limited extent for flooring but for no other purposes in building construction.

*Yellow Poplar* is a light, soft, straight-grained wood which is classed as a hardwood although in its physical properties it resembles the softwoods. It takes paint well but is not attractive when stained. Poplar is used to a limited extent as siding and for interior and exterior trim.

*Gum* is a heavy, strong, close-grained and cross-grained wood. It shrinks and warps badly and requires considerable care in seasoning. It is very attractive when finished in its natural color and may be stained to resemble mahogany, walnut, cherry, and maple. Gum is extensively used for interior finish.

Other hardwoods which are very attractive but which are two expensive for use even as interior finish or trim are cherry, mahogany, and walnut. They are used for furniture and cabinet work.

# CHAPTER III

# FOOTINGS AND FOUNDATIONS

## ARTICLE 11. DEFINITIONS AND GENERAL DISCUSSION

The part of a building below the surface of the ground is often called the *foundation* or *substructure*, and the part above ground, and supported by the foundation walls is called the *superstructure.*

In this chapter only the part of a building which rests directly on the earth and transmits the weight of the building and its contents to the earth will be considered as the foundation. Walls below the surface of the ground and resting on the foundation will be called foundation walls. These walls are described in Article 22.

In order that the bearing power of the soil supporting a building may not be exceeded it is necessary to distribute over a large area the load carried by the foundations. This is done by widening the part of the foundation which comes in contact with the soil. The enlarged part of the foundation as shown in Fig. 5 is called a *footing.* Even though the soil pressures are kept within reasonable limits it is not possible to avoid all settlement in buildings placed on ordinary soil but the objections to settlement are largely avoided if the settlement is the same for all parts of the building. The settlement is caused by loads which are in place for long periods of time such as the weight of the building and permanent furniture and equipment. In order to secure uniform settlement it is common practice to proportion the footings in such a way that the soil pressure per unit of area of the footing for permanent loads is the same for all footings, but in no case should the unit soil pressure for the total load exceed the allowable value. If the soil on which a building rests does not have uniform bearing strength over the entire area, appropriate adjustments must be made in the estimate of the soil pressure used in proportioning the footings. The problem is quite difficult when a part of the building rests on solid rock and the remainder on a yielding soil. In this case very low pressures must be used for the part resting on the soil or settlement cracks will develop.

The defects in this method of proportioning for uniform settlement have been pointed out by Professor Charles Terzaghi,[1] who states that:

(*a*) The relation between the diameter of the loaded area and the settlement produced by a given unit load depends essentially on the cohesion (actual shear-

[1] *Proceedings* of American Society of Civil Engineers, November, 1927, p. 2268.

ing strength) of the soil. For soils with great cohesion the settlement produced by a given unit load increases in direct proportion with the diameter of the loaded area. On the other hand, for perfectly cohesionless soils, the size of the loaded area has little effect.

(*b*) With increasing depth of foundation, the settlement produced by a given unit load decreases. However, the ratio between the settlement for a foundation depth of zero, and a corresponding settlement for a depth, $t$, does not depend on the value of $t$ alone, but on the ratio, $t/d$, between the depth of foundation and the diameter of the loaded area.

(*c*) The effect of the ratio, $t/d$, on the settlement is less, the greater the cohesion. For perfectly cohesionless materials, a ratio of $t/d = 1$ (depth of foundation = diameter of loaded area) almost triples the bearing capacity and reduces the settlements to one-third of what they would be if the footing rested on the surface of the ground.

It is customary to assume that the soil pressure on a footing is distributed uniformly over the entire bearing area:

However, according to the measurements carried out by M. L. Enger the distribution of the soil reactions over the base of a rigid slab is by no means uniform. The pressures are equal to zero at the edge of the slab and are greatest at the center, the pressure curve having a parabolic shape.[1]

The material on which foundations rest may vary from soft clay or quicksand with very little bearing power to solid rock. The following table taken from the Building Code of the National Board of Fire Underwriters will illustrate the wide variation in the allowable soil pressure of different materials on which a building may rest:

| | *Allowable Soil Pressure, Tons per Square Foot* |
|---|---|
| Soft clay | 1 |
| Firm clay, fine sand, or layers of sand and clay, wet | 2 |
| Clay or fine sand, firm and dry | 3 |
| Hard clay, coarse sand, gravel | 4 |
| Hardpan | 8 to 15 |
| Rock | 15 to 72 |

With the possible exception of hardpan these terms do not need definition. *Hardpan* is a mixture of sand and gravel cemented together with clay, iron oxide or other material.

The values given are used if a better estimate of the bearing power has not been determined by tests as described later in this article.

**Investigations of Site.** — Before a building site is purchased, or at least before foundation plans are prepared, an investigation of the site

[1] *Proceedings* of American Society of Civil Engineers, November, 1927, p. 2270.

should be made to determine the character of the underlying material which will be called upon to support the building.

An investigation of the site should determine the character of the soil to a depth somewhat greater than that of the bottom of the foundation, the elevation of the ground-water level if above the bottom of the foundations. Where there is any doubt of the bearing power, test loads should be applied to the soil. The probable effect of adjoining structures should be studied and data should be secured from others who have erected buildings in the vicinity. If the material is dry, the effect of its becoming wet should be considered, and if wet, the bearing power is often increased by draining, but may be decreased.

The character of the soil may be determined in several ways which are more or less satisfactory. *Test pits* may be dug if the foundations are not to be very deep. Such pits afford an excellent opportunity for inspecting the soil in its natural state.

A *rod* or *pipe* with pointed end may be driven into the ground through soft strata to determine the depth to firmer material with greater supporting power. The rod is driven with a maul and turned after each blow to prevent sticking. Such an investigation yields little data on the character of the material, but if the rod may be driven to depths to which it is not practicable to carry the foundations the tests would indicate that within this limit no hard material is available for foundations. If the rod strikes firm material near enough to the surface to be of value in supporting foundations further investigation should be made to determine the nature of this material, for it may be only a thin layer of hard material, or a boulder encountered in driving. If a pipe is used and the ends are left open, the driving may be accomplished by forcing water down through the pipe. The water will escape at the lower end, washing the material away and making it possible to work the pipe down into the ground.

A *wood auger* fastened to a long pipe or rod may be used to bore to considerable depth in certain materials, such as clay or damp sand, bringing up samples of the materials encountered by removing the auger. The auger is turned by means of a handle fastened at right angles to the pipe.

Sandy materials may cave in and obstruct the hole. In this case the auger may be operated inside of a pipe casing, the casing being driven down as the boring progresses. This method is not usually satisfactory, particularly where boulders, gravel or compact materials are encountered; however, a chisel point may be used instead of the auger to drill through occasional obstructions. This method is usually limited to depths of about 20 ft.

A *water jet* may be used inside of the casing instead of an auger. Water is pumped down the jet pipe and washes the material away from the lower end of the casing, which is forced down by rotating or driving where necessary. In hard material a chopping bit containing a jet is used. This is alternately dropped and raised and chops its way through the material. Samples of the material encountered are brought up by the water rising in the space between the casing and jet pipe. These samples serve only as an indication of the material for the fine and course particles are separated and the heavier particles may not be brought up. Clay often disappears entirely in the process. More accurate samples may be obtained by replacing the jet with a piece of pipe which is pressed into the material in the bottom of the hole. The pipe is removed and the material contained in it may then be inspected. Boulders, hardpan or rock may make further boring by this process impossible. Boulders are sometimes removed by withdrawing the jet pipe and dropping dynamite down the hole. The common sizes of pipe used for casings are 2 in., $2\frac{1}{2}$ in., and 3 in. This is known as the *wash boring method.*

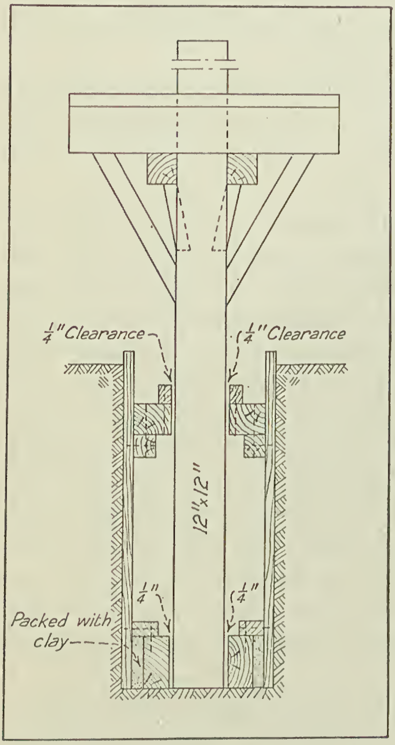


Fig. 4. Apparatus for Tests on Bearing Power of Soils

*Diamond drills* or *shot drills* are used to obtain samples from rock. These drills consist of hollow steel cylinders which are rotated in boring. Diamond drills are provided with black diamonds set in the lower edge of the cylinder to cut the rock, while shot drills secure their cutting action from particles of chilled cast iron called shot which are poured in the hole and forced against the rock by the rotating cylinder. These drills produce cores which are removed and inspected.

When the supporting power of a soil is uncertain, *loading tests* are frequently made. These tests consist of loading a certain area of soil, usually one square foot, but preferably larger, to determine what pressure can be safely used in designing the foundation. Levels are taken to

determine the amount of settlement of the test load. Some settlement must be expected but if the settlement is not excessive for pressure about twice as great as those proposed for the foundation design satisfactory results should be secured. A diagram of an apparatus used for testing is shown in Fig. 4. The platform is loaded with brick, pieces of cast iron, or other material to produce the desired pressure on the soil. Due to the uncertainty concerning the effect of the size of the loaded area and its depth below the surface and concerning the distribution of the soil pressure over the loaded area, such tests are of doubtful value.

**Depth and Area.** — Foundations should always be carried below the frost line to prevent movement of the building when the ground freezes. They may often be provided with a system of drains to increase the bearing power of the soil by removing the water or simply to secure a dry basement.

The area of the footing must be such as to distribute the wall or column load over such an area that the bearing pressures will not exceed the allowable value. When the loads are heavy, or the bearing power of the soil is poor, piles may be placed under walls or columns forming pile foundations. Wood piles are tree trunks with branches trimmed off. They are driven into the ground with the small end down, by a pile hammer. Piles are also made of concrete and, in some cases, of steel.

The columns of tall buildings are frequently supported by piers of concrete carried to hardpan or bedrock even though the surface of this material may be 100 ft. or more below the surface of the ground. The deepest foundations to date are those of the Cleveland Union Terminal Building where some of the piers were carried down to bedrock which was 210 ft. below the basement floor, and nearly 200 ft. below the ground-water level. Since such buildings are always of skeleton construction, no wall foundations are required, but a continuous wall of rectangular piers, as described in Article 14, may be used under wall columns to form a water-tight wall for basements which are at a considerable distance below the ground-water level.

**Excavations Affecting Adjoining Property.** — In excavating for the basement and foundations of a new building, it is very often necessary to make some provision to prevent the adjoining land from suffering damage by the caving of the banks and to prevent injury to the buildings on adjoining land due to disturbing or undermining the foundations. This may require that the foundations of such buildings be extended to greater depths.

At common law, the owner of a piece of land has the right to the lateral support of his land. If the lateral support is removed by excavating on the adjacent property some other provision for lateral support must be

made by the person responsible for the excavation. This right of lateral support relates only to the land in its natural condition and it does not include provisions which must be made to protect the buildings on the land. The proper division of the responsibility when buildings as well as the land itself must be supported is not a simple matter. To fix such responsibility more definitely the building codes of cities usually contain specific clauses concerning this matter. These clauses, if their legality is established, take precedence over the provisions of common law.

In many cities, if the depth of the excavation is not greater than a specified depth the owners of adjacent buildings must take the necessary steps to protect these buildings but if the excavation extends beyond this depth the persons causing the excavation to be made must assume responsibility for such protection unless the owners of the adjacent property refuse them the right of entering on their property to carry on this work. If the excavations are not to be carried below the specified depth the persons responsible for the excavations are required by the codes of some cities to protect the excavation so that the adjoining soil will not cave or settle even though they may not be required to make necessary extensions in foundations. If excavations are to be carried below the specified depth, many cities require that the owners of the adjoining buildings extend their foundations to the specified depth but the person responsible for the excavation must extend these foundations the necessary amount below that depth. This specified depth varies in different cities from 10 to 14 ft. below the street grade or elevation of the curb.

Some other cities require that the persons causing the excavation to be made must be responsible for all necessary protection of adjoining land and buildings regardless of the depth of the excavation. At least one city has taken the opposite position and makes it the duty of the adjoining property owners to protect their own buildings from damage due to excavations.

Considering the varying practice concerning the responsibility for the protection of adjacent property, a careful investigation of the local requirements should be made before preparing an estimate for a proposed building and before starting building operations.

## ARTICLE 12. FOOTINGS

**Classification of Footings.** — Footings may be divided into four classes depending on the type of construction: Simple footings, stepped footings, spread footings, and grillage footings.

Footings may be divided into wall footings and column footings depending on whether walls or columns are supported.

Column footings may be divided into five classes, depending on the number of columns carried by each footing, and upon the method used in carrying the loads. These classes are: Isolated, or single footings each supporting one column; combined footings each supporting two or more columns; cantilever footings, each supporting two columns; continuous footings, each supporting several columns in a row; and raft footings, each supporting a group of columns, usually all of the columns of a building.

**Simple Footings** project only a few inches beyond the edge of a wall or column, as shown in Fig. 5*a* and 5*b*. Such footings are used only for light loads, and the stresses in the materials are low. They are usually made of plain concrete, although hard-burned brick and flat stones have been used extensively in the past.

**Stepped Footings** may be used when the loads to be transferred to the soil are so great that wide footings are required. This type of footing for a wall is illustrated in Fig. 5*c* and for a column in Fig. 5*d*. If simple footings were used for the wide projections required by the heavy loads they would have to be made quite thick on account of the tendency of the projection to break off. It is evident that material can be saved by using the stepped footing under these conditions, instead of the simple footing. Stepped footings may be built of concrete, brick, or stone. Stepped footings have practically gone out of use.

**Spread Footings** are wide shallow footings constructed of concrete reinforced with steel rods placed on the lower side to keep the projections from breaking off. Spread footings for a wall are shown in Fig. 5*e* and for columns in Fig. 5*f* and 5*g*. In these figures it will be noted that the footings may have a rectangular vertical cross-section, or the top may be stepped or sloped to save material.

Footings with sloping tops contain the least material but are difficult to construct. There is a tendency to pour each step or block of a stepped spread footing separately allowing the concrete to set at least partially between operations but this practice must not be permitted because in design it is assumed that the whole footing acts as a unit.

The spread footing which has been stepped to save material must not be confused with the stepped footing which has no reinforcement and must therefore be much deeper than the corresponding spread footing.

The main reinforcement in a spread footing for a wall is perpendicular to the wall but light longitudinal reinforcement is also provided as shown in Fig. 5*e*. The reinforcement in a spread footing for a column may be arranged as shown in Fig. 5*f*, which is called two-way reinforcement, or as shown in Fig. 5*g*, called four-way reinforcement. Two-way reinforcement requires fewer different lengths of rods and is just as strong, and is

therefore to be preferred to four-way reinforcement. The bond stress in spread footings is usually so high that it is necessary to use small rods and to hook the ends of the main reinforcement to prevent slipping.

Spread footings are more desirable than stepped footings, because stepped footings occupy more space in the basement or if they are kept below the basement floor level, a greater amount of excavation and material is required. The weight of stepped footings is greater than that of spread footings for the same conditions.

**Grillage Footings** for columns are usually constructed of steel I-beams arranged in tiers and fastened together as shown in Fig. 5*h* the space between the beams being filled with concrete and the entire footing being encased in concrete to prevent rusting. Grillage footings have the same advantages as reinforced-concrete spread footings, but the latter type is more commonly used at the present time.

Grillage footings of timber as shown in Fig. 5*i* may be used for temporary buildings and have been used in the past for other buildings when the footings are below the permanent ground-water level. Timber when placed under water will last indefinitely, but the construction of sewers and subways may lower the ground-water level and leave the footings above water where they will soon decay.

**Combined Footings.** — Very often a wall column is within a few inches of the property line and if the usual type of footing were used the footing would project over the property line as shown in Fig. 5*j* or if kept back of the property line the column would have to be placed near the edge of the footing. This is not permitted because the bearing pressures would not be uniform over the area of the footing. Under these conditions combined footings or cantilever footings are used.

The building regulations of some cities permit foundations to project over the property lines when bounded by streets and alleys. This greatly simplifies the foundation construction in such cases.

A combined footing is one which is common to two columns, usually a wall column and an interior column. The footing is trapezoidal or rectangular in plan and so proportioned that the resultant of the two column loads will pass through the center of gravity of the trapezoid or rectangle. This insures a uniform bearing pressure over the entire footing. A reinforced-concrete combined footing is illustrated in Fig. 6*a* and a steel-grillage combined footing in Fig. 6*b*. It is evident that the wall column can be placed at the edge of the footing and still secure uniform bearing pressures. A combined footing for two interior columns carrying equal loads is illustrated in Fig. 6*c*.

**Cantilever or Connected Footings.** — The principle of the cantilever footing is illustrated in Fig. 6*d*. This arrangement gives uniform bearing

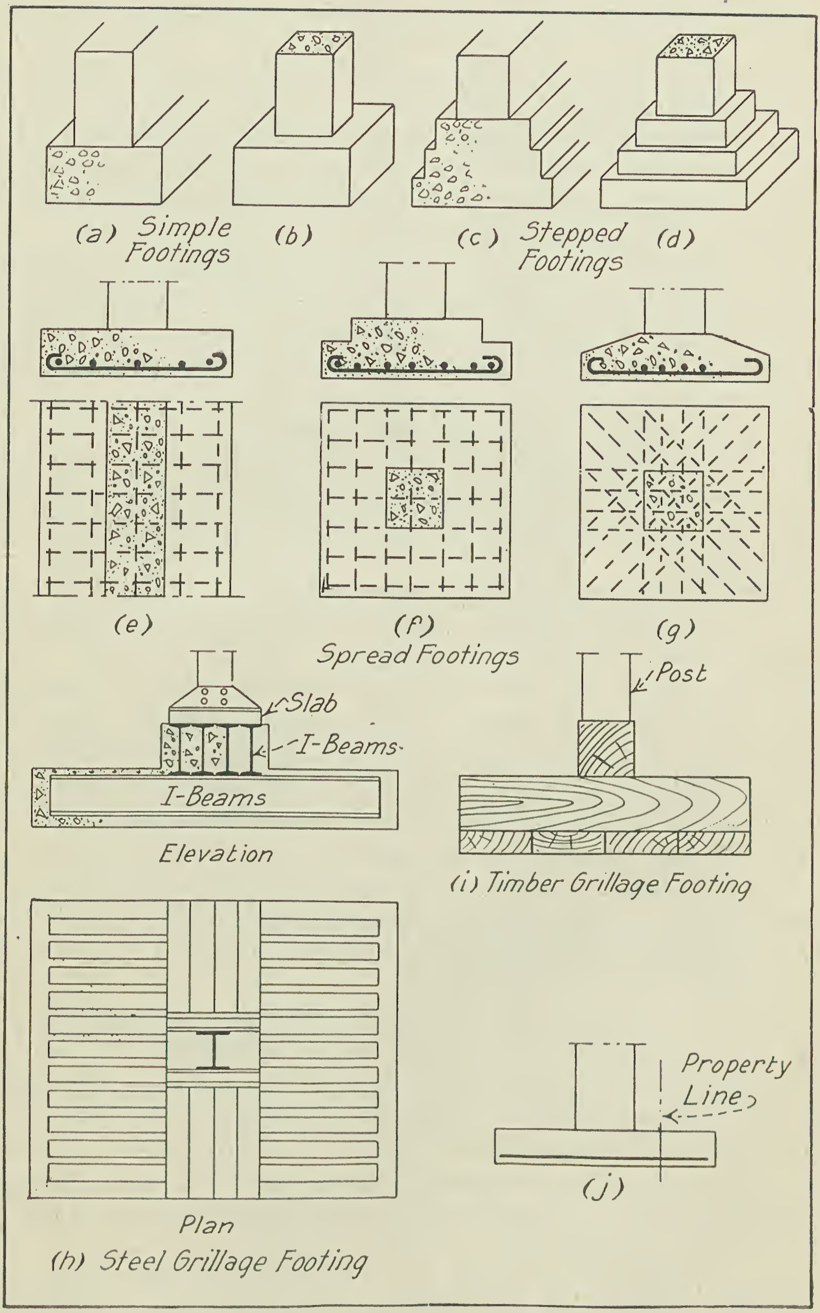



FIG. 5. Simple, Stepped, and Spread Footings

pressures under each footing and the footings can be proportioned so that the bearing pressures will be the same under the two footings. As actually constructed, there is no block or fulcrum separating the wall footing and the beam running between the two columns. However, the principle remains the same and any tendency of the wall footing to rotate, due to the eccentric position of the wall column and thus produce unequal bearing pressures, is resisted by the beam which joins the two columns or footings. This is called a strap beam.

This type of footing may be constructed of steel grillage beams or reinforced concrete. A steel grillage cantilever footing is illustrated in Fig. 6*e* and a reinforced-concrete cantilever footing in Fig. 6*f*. The cantilever principle is not always evident but an analysis of the footing may show that it exists. Cantilever footings are used for wall columns under the conditions mentioned under combined footings.

A reinforced-concrete cantilever footing used in conjunction with piles is illustrated in Fig. 8*c* and in conjunction with concrete piers in Fig. 13*a*. A steel cantilever resting on concrete piers is illustrated in Fig. 13*b*.

**Continuous Footings.** — A single footing may be constructed to carry a row of columns as shown in Fig. 6*g*. This is known as a continuous footing. Such footings are constructed of reinforced concrete. Concrete foundation walls are often constructed as beams to distribute column loads uniformly along a continuous footing. If the footing and the wall are to be poured separately, as is usually the case, the lower steel should be placed near the bottom of the wall as shown in Fig. 6*h*, but if they are to be poured in one operation, so that they will act as a unit, this reinforcing should be placed near the bottom of the footing.

**Raft Foundations or Mats.** — In some cases, reinforced-concrete footings are made of continuous strips running at right angles to each other and intersecting under the columns, as shown in Fig. 7*a*. These strips are designed as continuous beams.

A more common type of construction consists of a reinforced-concrete raft or mat as shown in Fig. 7*b*, under the entire building. These mats are reinforced with a layer of closely-spaced rods running at right angles to each other and about 6 in. below the top surface of the mat and another layer about 6 in. above the bottom. The thickness is sometimes as great as 6 or 8 ft., a common thickness being 5 ft. Such mats are usually poured in one operation to avoid construction joints, even though several days and nights may be required to complete the work.

Another common form of raft or mat consists of inverted T-beams of reinforced concrete with the slab covering the entire area, as shown in Fig. 7*c*. The beams run in both directions and intersect under the

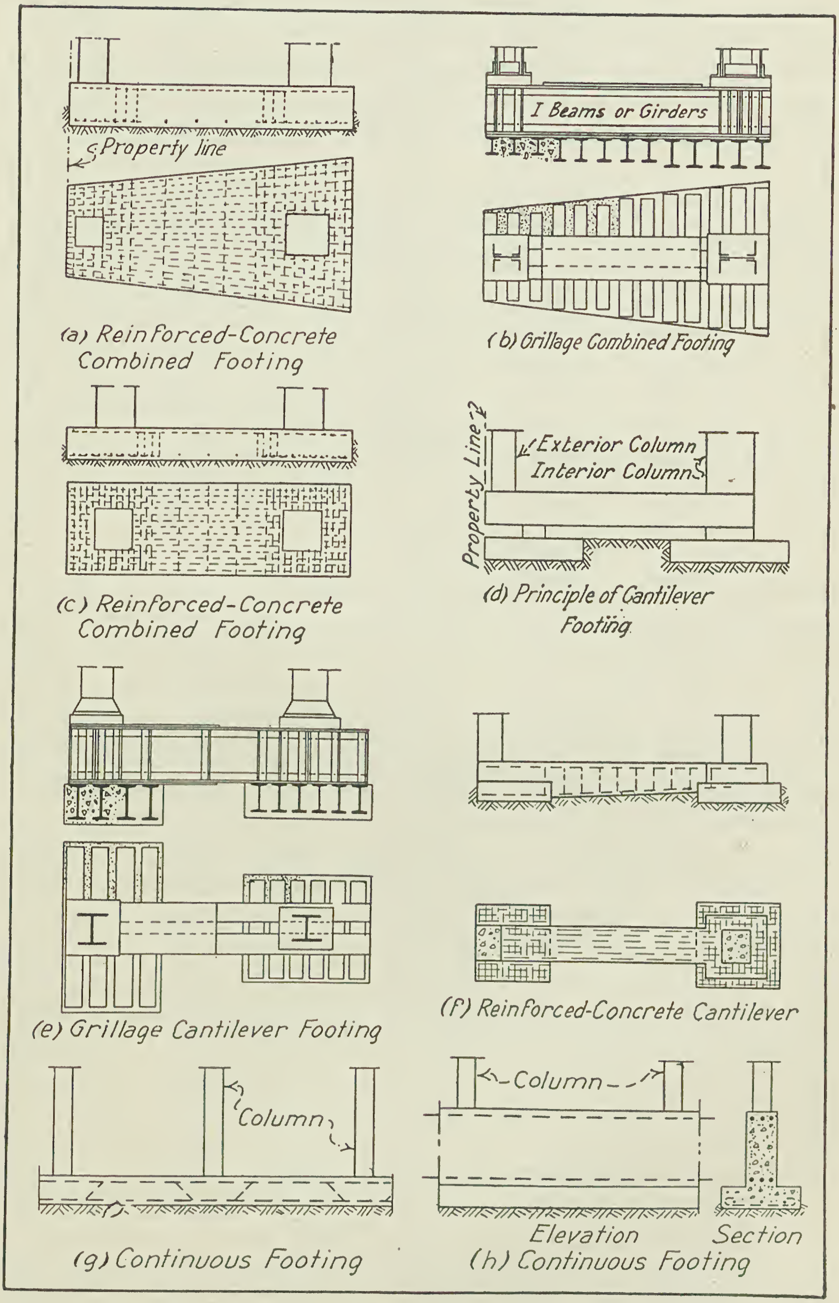



FIG. 6. Combined, Cantilever, and Continuous Footings

columns. Before the basement floor is placed it is necessary to fill in the space between these beams with cinders or other material.

In order that the mat may serve as the basement floor, and to save excavation and filling, the slab may be placed on top of the beams as

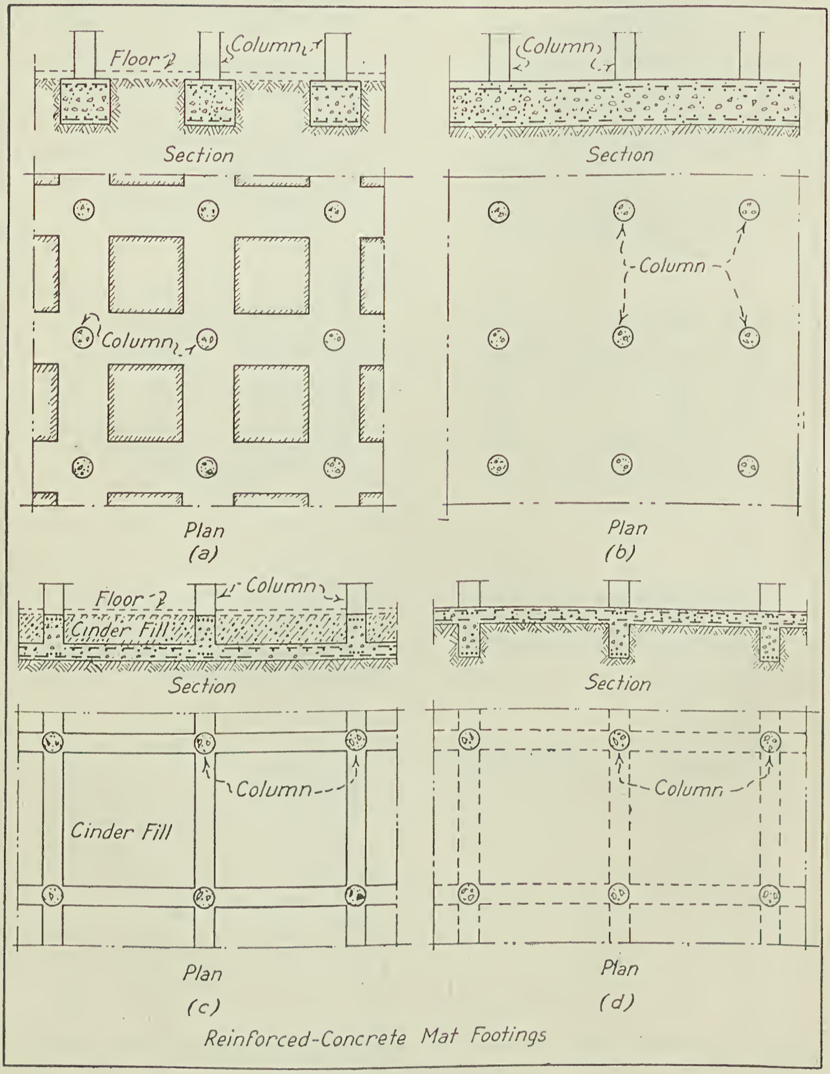



FIG. 7. Mat Footings

shown in Fig. 7*d*. This construction is suitable for a soil which will stand without caving so that the space required for the beams can be excavated and the whole mat poured without the use of forms. If it is

necessary to disturb any of the soil on which the foundation is to rest its bearing power will be reduced. Under these conditions this type of foundation should not be used. Favorable conditions for this type do not usually exist because if the soil is firm enough to stand the excavation required in placing the foundation its bearing power will be such that spread footings may be used.

Raft or mat foundations are used when the bearing power of the soil is so low that spread footings cannot be used and where the use of piles is not possible or not necessary. Mat foundations are quite frequently used for power houses where the machinery requires massive foundations. If they are to support steel columns, steel slabs or grillages may be required to distribute the column loads. These may be cast in the mat so that they will not obstruct the floor.

Piles are frequently used to support raft foundations, as explained in Article 13, but piles are not always effective in increasing the bearing power of a mat.

## ARTICLE 13. PILE FOUNDATIONS

When the foundation bed has a low bearing value, and heavy loads are to be carried, the footings described in Article 12 may not be adequate. Under these conditions, wood or concrete piles are frequently used to support walls or columns as shown in Fig. 8*a*. Such piles are called *bearing piles*. Piles may be driven into the ground by means of pile hammers or, in the case of some forms of concrete piles, they may be cast in place in a form or in a hole which has been prepared to receive them. A considerable saving may often be made by driving piles through soft material to a firm stratum as shown in Fig. 8*b* instead of using an ordinary footing placed on the firm stratum.

**Types of Pile Foundations.** — A simple pile footing for a column is shown in Fig. 8*a* and a cantilever footing supported by piles in Fig. 8*c*. Sometimes the size of separate pile footings becomes so large that they occupy most of the ground area under a building. In this case it may be desirable to use a continuous mat covering the entire area and supported by piles as shown in Fig. 8*d*. Such mats may be as thick as 6 or 8 ft. with layers of closely-spaced reinforcing bars running in both directions near the top and near the bottom. Piles placed under mats do not always increase the bearing power, as will be explained in the paragraph on "Bearing Power."

**Wood Piles.** — Wood piles are tree trunks with the branches trimmed off. They are usually driven with the small end down. This end may be cut off square, it may be pointed, or it may be provided with a metal point, called a *shoe*. When driving is not hard, unpointed piles are used,

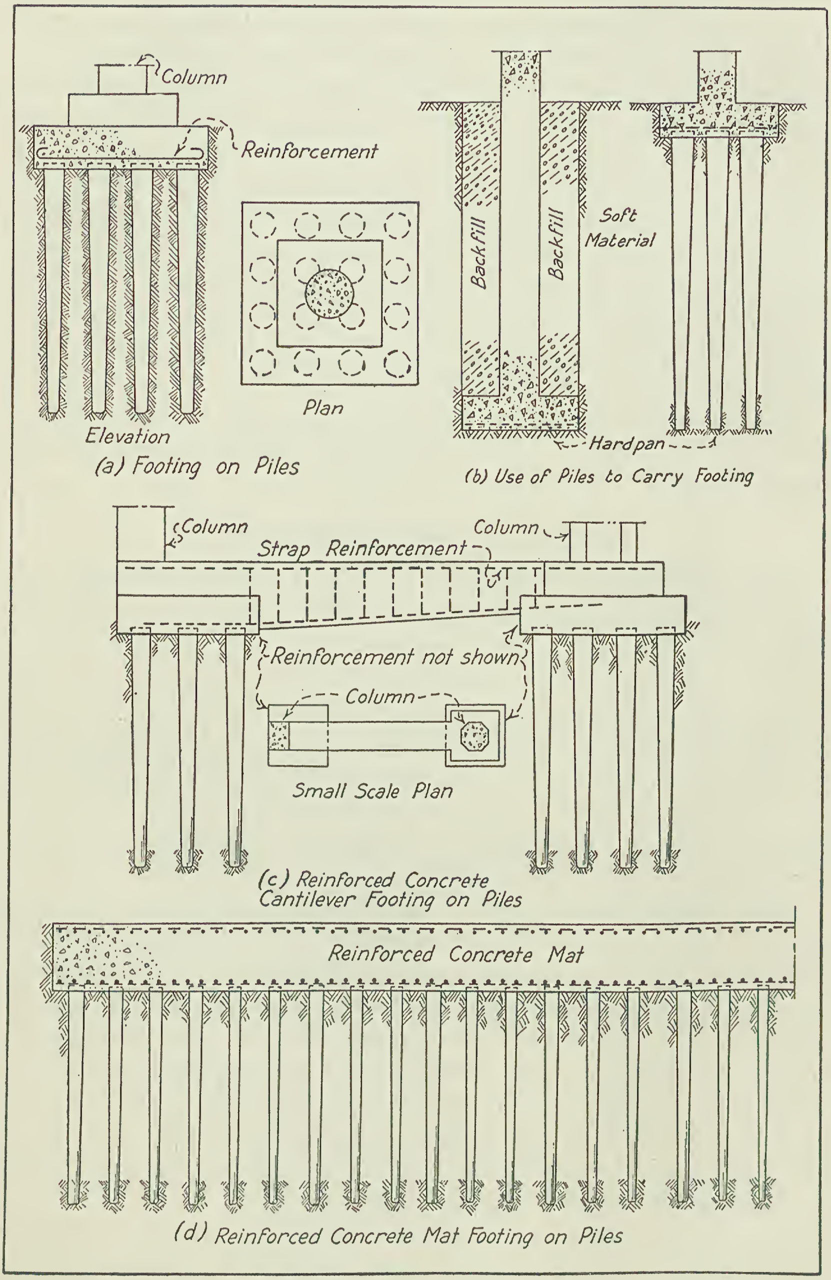



Fig. 8. Pile Footings

especially if the end of the pile rests on a hard stratum. Driving through firm clay may be made easier by cutting a blunt point on the piles; in driving through hardpan, shale, or material containing boulders, metal points may be desirable.

The Building Code of the National Board of Fire Underwriters requires timber piles to be sound and straight with a diameter at the butt of not less than 10 in., a diameter at the point of not less than 5 in., and any pile over 20 ft. in length must have a diameter at the butt of at least 12 in. Wood piles are sometimes required to be so straight that a straight line drawn from the center of the tip to the center of the butt would at no point lie farther from the pile than one-fourth of the diameter of the pile at that point. Sometimes it is required that this line lie wholly within the pile.

Wood piles are usually of spruce, fir, or yellow pine. Cedar, redwood, and oak piles are more durable than these woods when used above water, but they are more expensive. The decay of wood piles which are not submerged may be retarded by the use of some preservative treatment as described in Article 10. Piles which are submerged will not decay.

**Concrete Piles.** — Concrete piles may be precast or cast-in-place. Precast piles are cast in molds, allowed to harden, and are then driven. Cast-in-place piles are formed in place in the ground.

*Precast piles* may be round, square, or octagonal in section; they may be of uniform section or they may be tapered; and they may be made with or without metal shoes; but in all cases they are reinforced by steel bars running longitudinally and lateral reinforcement in the form of bands or spirals. The Building Code of the National Board of Fire Underwriters requires that precast piles must be provided with not less than 2 per cent nor more than 4 per cent of longitudinal reinforcement with bands or hoops not less than $\frac{3}{8}$ in. in diameter and spaced not farther apart than 6 in. The average diameter must be at least 12 in. and the diameter at the foot not less than 8 in. The length must not exceed thirty times the average diameter for piles driven through firm soil, and must not exceed fifteen times the average diameter for piles driven to rock through loose wet soil or filled ground. The tops of the piles must be protected with a cushion cap during driving, and when driven to rock the foot must be provided with a metal shoe having a square bearing.

One form of precast piles is shown in Fig. 9*a*.

*Cast-in-place* piles are of three types: the Simplex, the Raymond and the Pedestal types. In forming the *Simplex pile* a heavy steel tube provided with a point is driven into the ground, as shown in Fig. 9*b*. This tube is filled with concrete and withdrawn. The concrete is held in place and rammed with a heavy weight as the tube is being removed. A

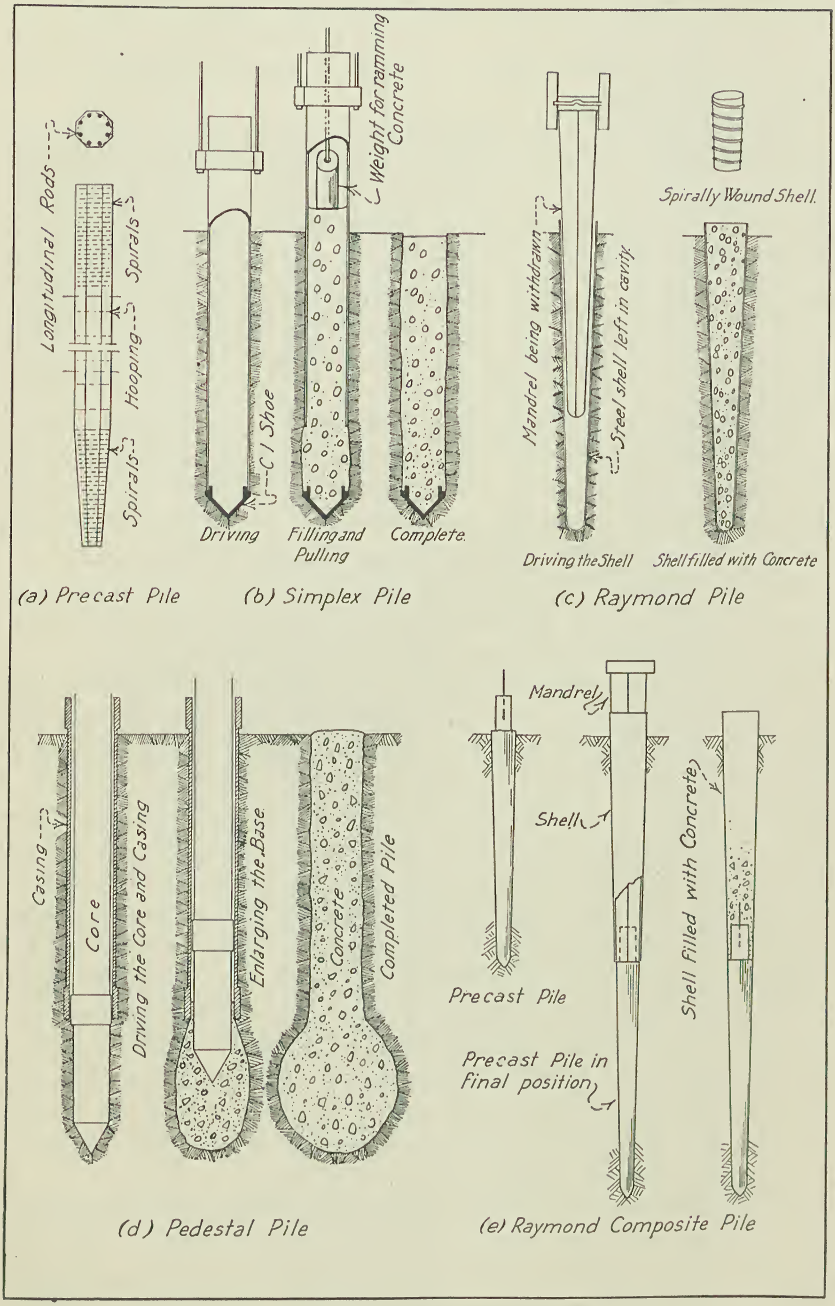



FIG. 9. Types of Concrete Piles

drop-bottom bucket which fits inside of the tube is used in depositing the concrete.

In forming the *Raymond pile* a thin steel casing with spiral reinforcement is placed over a steel core or mandrel. The casing and the core are driven into the ground and the core is collapsed and withdrawn leaving the casing in position. The casing is then filled with concrete. This type of pile is illustrated in Fig. 9*c*.

*Pedestal piles* are cast-in-place piles with an enlarged foot to provide greater bearing power. They are formed in a manner similar to Simplex piles, but have a plunger inside of the pipe and projecting below the bottom of the pipe. The pipe and plunger are driven into the ground as shown in Fig. 9*d*. The plunger is withdrawn and concrete is deposited in the bottom of the hole. The plunger is then driven into this concrete, forcing it out as shown. This process is repeated until the pedestal is of the desired size. The stem is then formed by depositing concrete in the pipe and withdrawing the pipe as the stem fills.

Cast-in-place piles are usually circular in section. The first type described is uniform in cross-section and the second type is tapered. Such piles are not reinforced.

The Building Code of the National Board of Fire Underwriters requires that cast-in-place piles must be made in such manner as to insure the exclusion of any foreign matter, and to secure a uniform full-sized section for the entire length. The average diameter of the pile is required to be not less than 14 in. and the diameter of the foot not less than 8 in. The length must not exceed twenty-five times the average diameter.

The maximum length of the common forms of cast-in-place concrete piles is about 40 ft. and the maximum allowable load about 30 tons.

**Composite Piles.** — Wood piles and cast-in-place concrete piles are combined to form composite piles. The method used in forming the Raymond composite pile is illustrated in Fig. 9*e*. A wood pile is first driven full length into the ground. This pile has a shoulder over which fits a steel mandrel and a sheet-steel casing as used for the common type of Raymond pile. The mandrel is then driven into the ground and forces the wood pile ahead of it until the final position is reached. The mandrel is withdrawn and the casing is filled with concrete forming a concrete pile on top of the wood pile.

Composite piles may be used for greater lengths than the ordinary cast-in-place piles. They are so placed that the timber section is below the permanent ground-water level, so that it will not decay.

**Comparison of Types of Piles.** — Wood piles can be used only when placed below the permanent ground-water level, whereas concrete piles do not have this limitation. Concrete piles are more expensive than

wood piles but the bearing power of a concrete pile is greater than that of a wood pile and fewer piles are required for a given load.

When all of these factors are considered, a concrete-pile foundation may be cheaper than a wood-pile foundation. The foundations in Fig. 10*a* show that under certain conditions there will be a considerable saving in excavation and masonry if concrete piles are used instead of wood piles which must be kept below the ground-water level. There is also a saving in the number of piles and the size of the cap if concrete piles are used. The saving in masonry due to the use of concrete piles will reduce the load to be carried by the piles.

Precast concrete piles may be injured in driving, if proper precautions are not taken, and Simplex piles may be injured when "green" by the driving of adjacent piles and the wet concrete may be diminished in section by the caving in of the surrounding earth. Where a pile acts as a column, longitudinal and lateral reinforcement is desirable, therefore precast piles are preferable to cast-in-place piles in which the use of reinforcement is not usually practicable. The pedestal on pedestal piles may be eccentric if the soil is not uniform on all sides. This condition causes bending stresses in the stem which may break the stem and impair the effectiveness of the pile.

**Piledriving.** — Wood piles and precast concrete piles may be driven by means of a piledriver, as shown in Fig. 10*b*, operating in conjunction with a drop hammer, a steam hammer, a pneumatic hammer, or a water jet.

When using a drop hammer, the pile is lifted into vertical position by the piledriver. A heavy weight called a *drop hammer* as shown in Fig. 10*c* is then dropped on the head of the pile, driving it into the ground, the weight being guided in its fall by the *leads* of the piledriver. The hammer is raised by a steam engine, a gasoline engine or an electric motor and the process is repeated until the desired penetration has been secured.

The *steam hammer* is extensively used instead of the drop hammer for driving. It rests on the head of the pile all of the time while driving, its driving power being derived from the reciprocating parts of the hammer itself which strike relatively light blows in such rapid succession that the pile is kept in continuous motion. Steam hammers are of the single-acting and the double-acting type. A *single-acting steam hammer* consists of a heavy ram which is raised from 2 to 4 ft. by admitting steam under pressure to a cylinder located above the ram and which falls by gravity when the steam is exhausted. The steam pressure acts against the under side of a piston in the cylinder and the piston is connected to the ram by a piston rod. The ram is guided in its fall and the various parts are held together by a frame as shown in Fig. 10*d*. The hammer

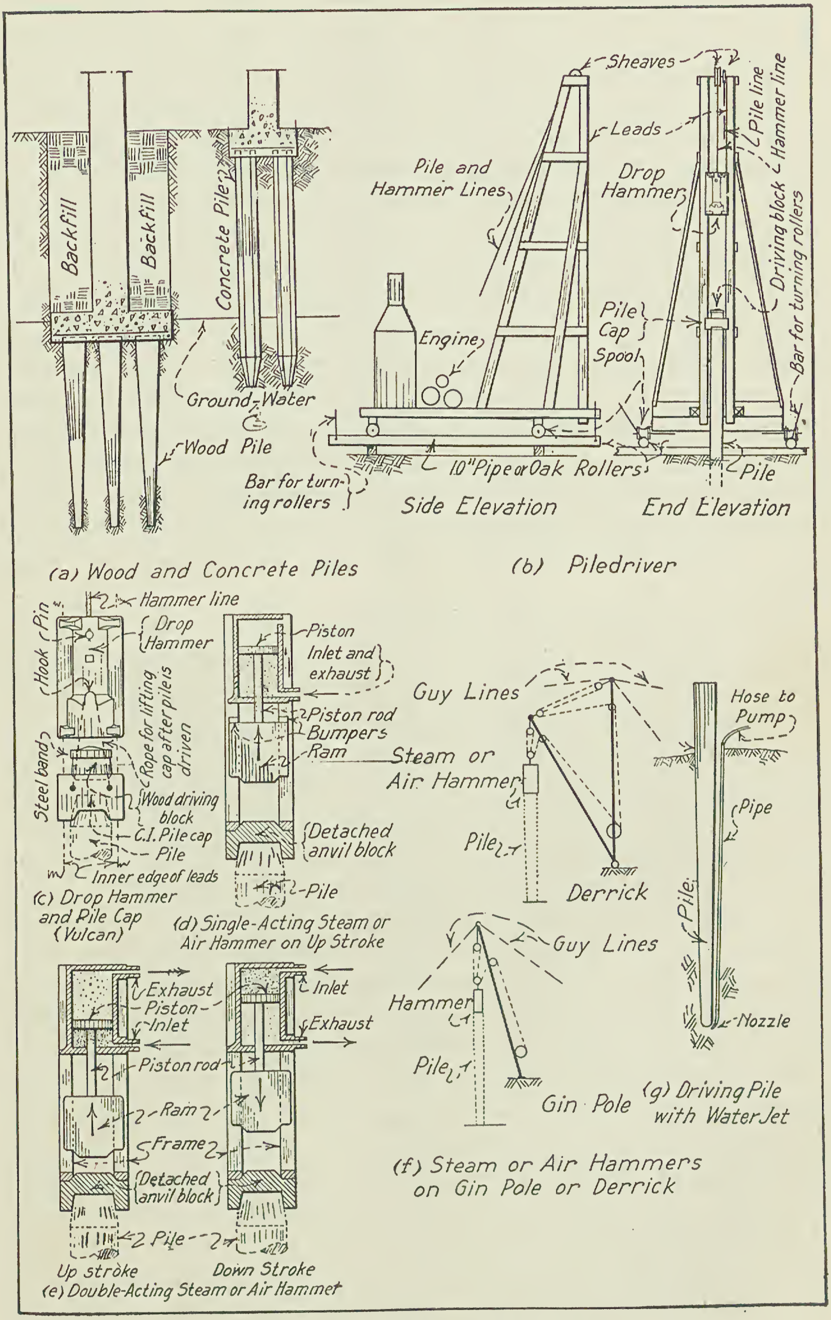



FIG. 10. Piles and Pile Driving

is placed in position on top of the pile by using a piledriver or by suspending it from the boom of a derrick or from a gin pole as shown in Fig. 10*f*. A *double-acting steam hammer* is similar to a single-acting hammer. The ram is raised from 4 to 20 in. by steam admitted under pressure to the cylinder on the lower side of the piston but instead of falling by gravity alone, as in the single-acting hammer, the ram is forced down by steam under pressure admitted to the cylinder on the upper side of the piston at the same time as the steam on the lower side is exhausted. The principle of the double-acting hammer is shown in Fig. 10*e*.

Special devices are used for protecting the heads of concrete piles during driving and to fit over the heads of sheet piles. The weights of steam hammers vary from 100 lb. to 16,000 or 18,000 lb. to meet the varying requirements. The light hammers are designed for a man to operate, without a piledriver, derrick or block and tackle, in driving sheathing. Steam hammers may be operated with compressed air as *pneumatic hammers*. Some types may be arranged to operate under water. Steam hammers may be inverted for use in pulling sheet piles and sheathing. Steam hammers drive piles more rapidly than drop hammers and injure them less.

The *water jet* is extensively used in driving piles. It consists of a pipe placed at the side of a pile, as shown in Fig. 10*g*, through which water is forced, washing the material away from the point of the pipe. The pile drops into the space formed by the water jet. Some of the water from the jet rises to the surface along the sides of the pile and acts as a lubricant in decreasing the friction of the surrounding earth, thus assisting materially in driving. A load may be placed on the pile to assist in forcing it down or light blows may be struck with a pile hammer. In addition to the jet which delivers water to the point of the pile, jets may be used to deliver water along the side of the pile to assist in decreasing the frictional resistance. After the driving by the jet is completed the earth settles around the pile and develops frictional resistance to correspond with that developed in driving without the jet. The final penetration is usually given with a pile hammer after the jet has been turned off.

The pipe used in jetting is about $2\frac{1}{2}$ in. in diameter with the lower end decreasing in diameter to about $1\frac{1}{2}$ in. to form a nozzle. The upper end of the pipe is connected to a force pump by means of a hose. Concrete piles often have the jet pipe cast-in-place along the axis of the pile. Piles driven with a water jet are not injured in driving; so this method is particularly suitable for precast concrete piles. The water jet may be used in many classes of material but it operates most successfully in sand. This is a fortunate condition, since sand offers the greatest resistance in driving with the pile hammer.

**Bearing Power of Piles.** — The bearing power of a pile depends upon the strength of the pile and upon the support which the surrounding earth gives to the pile. The strength of a pile can be computed with reasonable accuracy but the supporting power of the earth is difficult to determine. If a pile is driven through soft earth with little or no supporting power and bears on a firm stratum of hardpan or rock the pile acts as a column and its strength is computed accordingly.

There are two methods in common use for estimating the bearing power of a pile as determined by the supporting power of the surrounding earth. The most common method consists of calculating the bearing power from the energy required to drive it. The other method consists of loading the pile with a test load and observing its behavior. Each of these methods will be considered.

In estimating the bearing power of a wood pile from the energy required to drive it, the *Engineering News* or *Wellington* formula is extensively used. According to this formula the allowable load on a pile driven with a drop hammer or a single-acting steam or pneumatic hammer is

$$P = \frac{2\,Wh}{s + c}$$

where $P$ = the allowable load in tons, with a supposed factor of safety of six.
$W$ = the weight of the drop hammer or the ram in tons.
$h$ = the height of free fall of the drop hammer or the ram, in feet.
$s$ = the penetration of the pile, in inches, due to the last blow of the hammer or ram. This is usually taken as equal to the average penetration for the last six blows or the last ten blows.
$c$ = a constant which is taken as 1.0 when a drop hammer is used and as 0.1 when a steam or pneumatic hammer is used.

This formula does not apply to double-acting steam or air hammers for in these the ram moves downward due to the combined action of its weight and the steam or air pressure. The energy per blow exerted by the ram depends upon the steam or air pressure used. It can be shown that the energy per blow cannot exceed the total weight of the hammer, including the ram, multiplied by the length of stroke of the ram, because if pressures are used which exceed that required to produce this amount of energy, the hammer will be lifted from the pile. In the *Engineering News* formula, $Wh$ represents the energy acquired by the drop hammer or ram, the weight of which is $W$, in falling a distance $h$, and is therefore the energy per blow. The energy per blow for the double-acting steam hammer is taken as $E$, its value being given by the manufacturers. The value of $E$ is taken as for 75 to 100 per cent of the product of the total

weight of the hammer and the length of stroke of the ram. By substituting the value of $E$ for $Wh$, the *Engineering News* formula is made to apply to double-acting hammers.

The *Engineering News* formula does not take into account many factors which affect the relation between the bearing power and the energy required to drive a pile and thus may give results which are greatly in error. An excellent discussion of this subject is given in a paper entitled, "*The Science of Foundations,*" by Dr. Charles Terzaghi in the *Proceedings* of the American Society of Civil Engineers for November, 1927, from which the following quotations are made:

In certain materials (particularly in sand, gravel, and permeable artificial fills), the resistances acting while the pile is being driven are practically identical with those acting on the pile under static load. Under such conditions the pile-driving formulas can be expected to furnish results with sufficient accuracy. . . . However, for this case experience seems to show that the formulas based on the theory of impact furnish far better results than the *Engineering News* formula.

In other materials (very fine-grained silts, soft clays, etc.), the friction acting on the pile during the driving (hydrodynamic pile friction) is very much less than that which develops after a couple of days' rest (static pile friction), while the resistance of the point of the pile under impact (dynamic point resistance) is much greater than its resistance under static load (static point resistance). . . . The application of any piledriving formula to the bearing capacity of piles driven into the second class of materials is a gamble, trusting that the deficiency in skin friction associated with the driving of the pile may, by chance, be compensated by the corresponding excess of point resistance.

According to Charles Terzaghi, the *Engineering News* formula furnishes values which are far too low where the penetration is less than one inch, the error rapidly increasing with the decreasing depth of penetration.

The bearing power of precast concrete piles is sometimes computed from this formula, but due to the great weight of such piles the formula is even less reliable than when applied to wood piles. The bearing power of cast-in-place piles is often estimated by assuming that it is equal to the bearing power of the steel shell as determined from the *Engineering News* formula. This is a further step into the realm of uncertainty. The final penetration of piles which are jetted down is often secured by using a pile hammer. The *Engineering News* formula is applied to this case also.

The most satisfactory method for determining the bearing power of a pile is by means of a loading test. In this way it is possible to subject the pile to the same treatment which it will receive when performing its

function. This is the only reliable method to use for wood piles in some soils where the piledriving formulas give unsatisfactory results and for concrete piles in any kind of soil. Many building codes state that the allowable load on a pile shall not be greater than one-half of the maximum load which causes no settlement for 24 hours and the total settlement shall not exceed 0.01 in. per ton of test load. The cost of loading every pile with a test load would be prohibitive; therefore only enough piles are loaded and tested to give representative values which indicate the allowable loads to use for the remainder of the piles.

In estimating the bearing power of a group of piles such as is used under a wall or a footing, the total bearing power of the group is assumed to be equal to the bearing value of one pile multiplied by the number of piles in the group. This cannot be true when the piles are supported by skin friction, because the load carried by a single pile is distributed over a considerable area of the surrounding earth and due to the close spacing of the piles in a cluster or group this area does not increase directly with the number of piles since the individual areas overlap. This discrepancy is very pronounced in the case of raft foundation or mats supported by piles. In certain soils the driving of piles compacts the soil and increases its bearing power. This tends to offset the discrepancy between the proportionate bearing value of a single pile and a group of piles.

Professor Terzaghi[1] calls attention to the conditions under which the bearing power of a foundation may not be increased by using piles. This condition exists in a wide foundation, such as a mat, bearing on a very deep deposit with a fairly uniform consistency.

The bearing power of precast or cast-in-place concrete piles and of jetted piles can be determined satisfactorily only by loading tests.

**Maximum Load and Minimum Spacing.** — The maximum load allowed on wood piles, regardless of their strength and the results of any calculated bearing values or loading tests, is usually taken as 20 tons, on cast-in-place concrete piles 30 tons, and on precast concrete piles 50 tons. The direct bearing value of the soil between the piles is neglected in design.

It is not considered good practice to drive piles closer together than $2\frac{1}{2}$ or 3 ft. center to center, for if a closer spacing is used the bearing power of each pile may be so decreased that no advantage is gained by the closer spacing and the cost is increased. This minimum applies only to the case where the piles are supported by skin friction and not to the case where the lower ends of the piles rest on a hard stratum.

**Other Requirements.**[2] — A detached column footing should not rest on less than three piles unless it receives lateral support in all directions.

[1] *Proceedings* of the American Society of Civil Engineers, November, 1927.

[2] Building Laws of the City of Boston.

Light walls supported laterally at intervals of 10 ft. or less may safely rest on a single row of piles. In general, walls should rest on at least two rows of piles. For low walls less than 30 ft. in height the lateral spacing of the piles may be as small as 2 ft. center to center but for walls of greater height the spacing should be at least 3 ft.

**Pipe Piles.** — Pipe piles as shown in Fig. 11 are extensively used to develop a high bearing capacity in a small space. They have been found especially useful in underpinning buildings adjacent to areas where deep excavations are to be made for new buildings. They consist of steel pipes with open ends, which are forced through the ground preferably to bedrock, and are filled with concrete after removing the enclosed earth.

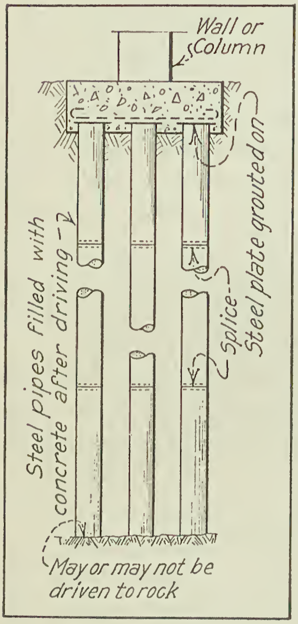



Fig. 11. Pipe Piles

The pipes are $\frac{5}{16}$ in. or $\frac{3}{8}$ in. in thickness and vary from 10 to 16 in. in diameter. These are placed in sections up to about 20 ft. with ends accurately faced perpendicular to the axis. These sections are spliced by cast-steel internal sleeves or couplings. Piles have been used up to 100 ft. in length with several splices. Some building codes[1] do not permit more than one splice in the length of a pile and limit the length to forty times the inside diameter. They also require that a deduction of $\frac{1}{16}$ in. or $\frac{1}{8}$ in. be made from the thickness in calculating the strength.[1] This deduction is to make allowance for corrosion. Piles which have been in place for 25 years have been exposed and show very little corrosion. Loads as high as 100 tons are carried by the larger sizes of pipe piles bearing on bedrock. Reinforced-concrete pile caps or footings, similar to those used on the common forms of piles, or steel grillages are used on pipe piles.

Pipe piles are driven by pile hammers with or without the assistance of water jets or by jacks in underpinning jobs where the building gives a load to jack against. Since they are driven with open ends, the pile fills with earth during the driving process. This earth is cleaned out by working a $2\frac{1}{2}$- or 3-in. pipe down inside of the pile and forcing air or water under high pressure into the pipe. The material is blown out as the pipe is forced down, leaving the inside of the pile clean down to the bed-

[1] New York City and the National Board of Fire Underwriters.

rock on which it rests. The pipe may also be cleaned out with a small orange-peel bucket. The rock surface may be tested for soundness by tapping with a steel rod placed inside of the pile and may be inspected by lowering a light globe into the pile. Before the concrete is placed any water which has accumulated in the pile should be removed if possible. This may be blown out by compressed air or may be pumped out if the bottom contact is tight enough to keep water out until the concrete can be placed. One method of sealing the bottom quickly after the water is removed is to drop a loosely filled sack of concrete into the bottom to serve as a plug. If the water cannot be removed the concrete may be placed with drop-bottom buckets. The use of such buckets may be desirable in long piles to avoid any possibility of segregation due to the falling of the concrete even though water is not present. After the concrete in the pile has set a steel plate is carefully grouted in place over the upper end of the pile to secure good bearing on the steel and on the concrete. Pipes bearing on sound bedrock will support any load the pile can carry but under other conditions loading tests may be required to determine the bearing power.

Foundations can be more rapidly constructed by using pipe piles than with caissons and very satisfactory results may be secured where this form of construction is appropriate.

## ARTICLE 14. CONCRETE PIERS

Tall buildings are frequently supported on concrete piers carried to the depth required to reach a material such as hardpan or bedrock which will have the necessary bearing power. See Fig. 12*a*. Such buildings are always of steel or reinforced-concrete skeleton construction, wherein the foundations are called upon to support columns and not bearing walls. The column load is distributed over the pier by grillage beams or by rolled or cast-steel slabs as shown in Fig. 12*d*; these are frequently 6 in. and more in thickness. The top 2 or 3 ft. of such piers are commonly reinforced with steel spirals or hoops as shown in Fig. 12*d*.

If a pier is to rest on bedrock which is at least as strong as the concrete, the uniform section shown in Fig. 12*a* is used. If the supporting material is hardpan the bearing area must be greater than the required area of the pier, therefore the pier is belled out as shown in Fig. 12*b* in soils such as clay, which will stand without support while the bell is being excavated. The side slopes of the enlarged section usually make an angle of about 60 deg. with the horizontal. The sides are again made vertical for a distance of about 12 in. at the bottom. If neither bedrock or hardpan can be reached within reasonable depths the multiple-bell pier shown in

Fig. 12*c* is sometimes used in clay soil which will stand without support while the bells are being excavated. By using several bells or enlargements, bearing is secured at intervals along the pier as well as at the bottom, so that the total bearing value of the pier is increased considerably. This multiple bell pier has been patented by Charles E. Fowler.[1] Other types devised by him make use of projecting brackets on the side of the piers instead of the continuous bell. Uniform bells are usually used.

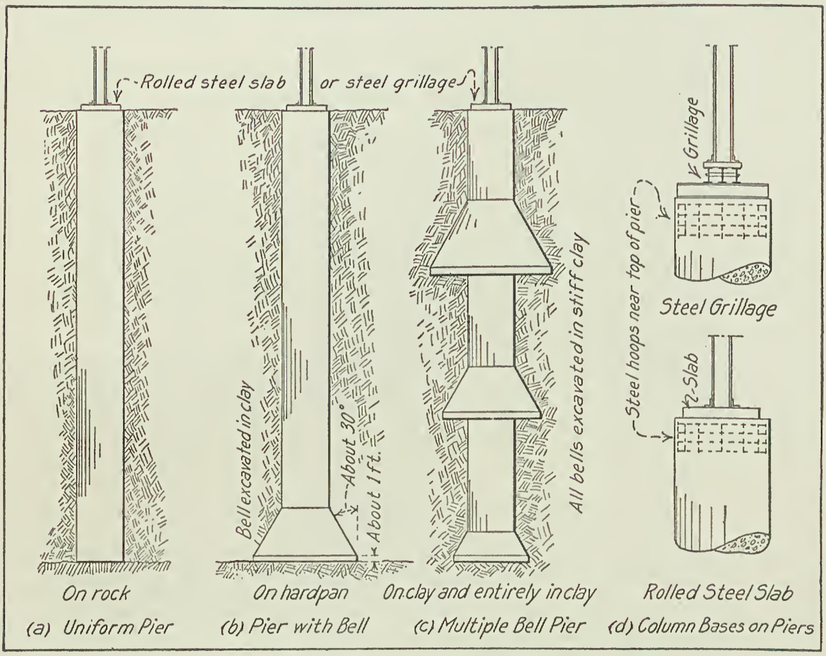



Fig. 12. Concrete Piers

Various methods of excavation for piers are used, the method adopted in any case depending upon the depth of excavation, the character of the soil, and the amount of water present.

In all of these methods some device such as sheathing, sheet piles, or caissons is used to hold back the earth and keep out water. The sheathing or sheet piles may be removed as the concrete is placed in the well but ordinarily they are left in place. Caissons are always left in place and become a part of the piers. At one time brick and stone were used in the construction of the piers but now concrete is used exclusively. Timber and steel which are used during the process of excavating and which are left in place will not rot or rust if they are below the ground level.

[1] *Engineering and Contracting*, Vol. 60, p. 874.

The eccentric effect of wall columns adjacent to the property line is taken care of by reinforced-concrete or steel cantilever girders extending from the wall piers to the nearest interior columns as shown in Fig. 13*a* and 13*b*. The joint use of piers by two adjacent buildings is often arranged so as to avoid the expensive cantilever construction for wall column foundations.

The methods used for excavating wells for concrete piers may be divided into two general classes, with several subdivisions under each class as follows:

*Open well methods:*

- Simple excavation
- Vertical sheathing
- Poling boards
- Horizontal sheathing
- Sheet piling
- Steel cylinders

*Caisson methods:*

- Box caisson (not used on buildings)
- Open caisson
- Pneumatic caisson

In the open-well methods the excavation is carried on under atmospheric conditions, the earth and ground-water being held back in various ways. Caissons are used only where ground-water is present in large amounts. The earth is held back by the caisson but the excavation is carried on through the water or the water is held back by compressed air and the excavation is carried on by men working in the compressed air. Box caissons are not used where excavation is required and are not used for buildings.

The open-well methods can be classified as *cofferdams* if ground-water is present. In general, a cofferdam may be defined as a temporary structure built to exclude water from a given area so that work may be carried on in that area under atmospheric conditions. Some leakage is to be expected but this is controlled by pumping. Cofferdams cannot be used if the bottom of an excavation is not watertight or practically so.

Two or more of these methods are frequently combined in a single well where different types of soil are encountered as the excavation progresses.

The various methods used in excavating for piers will now be described.

**Simple Excavation.** — Wells or pits may often be excavated in compact clay with no support whatever to prevent caving and with no provision for keeping out water. The excavation is carried on with pick and

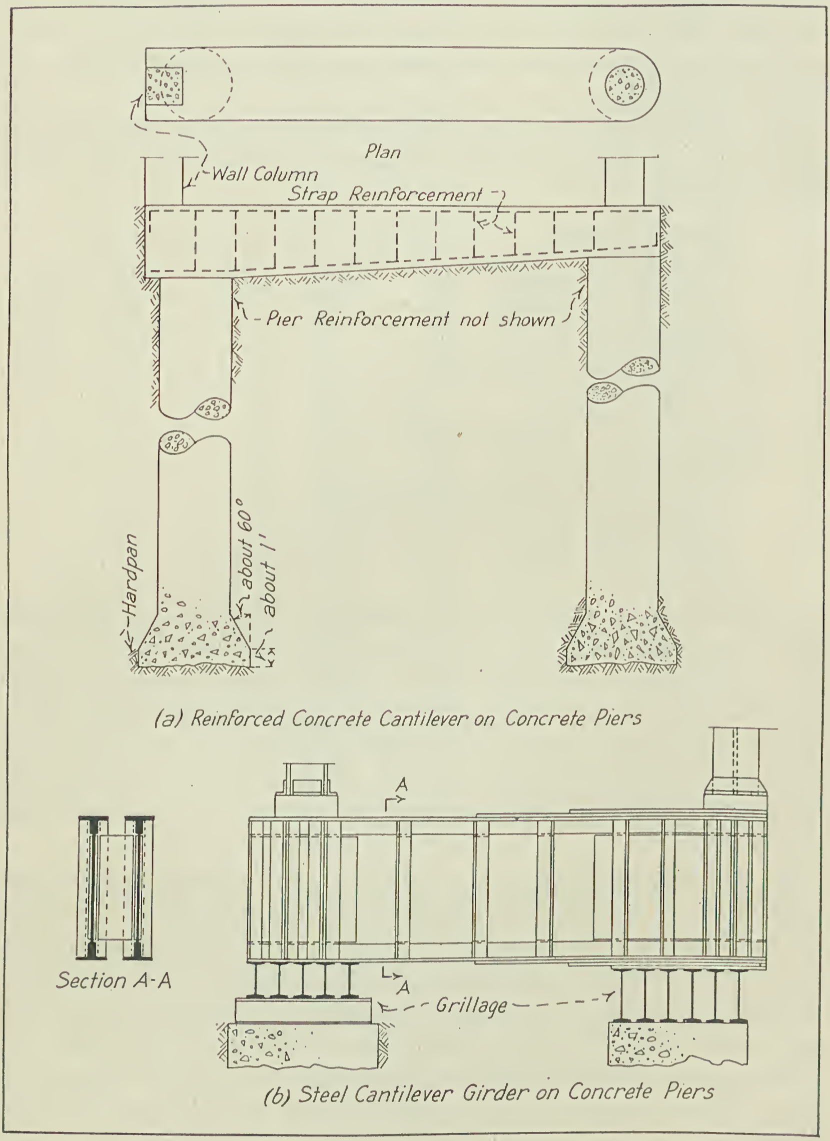



FIG. 13. Cantilever Girders on Concrete Piers

shovel in the usual manner or with air spades as described later, and the excavated material is removed in buckets hoisted by hand or power.

**Vertical Sheathing.** — In excavating wells or pits for concrete piers the earth sides may be held in place by sheathing. This sheathing may be of wood planks placed vertically and supported by wood frames consisting of longitudinal members called *wales* or *rangers* and transverse members called *braces*, as shown in Fig. 14*a*. The sheathing is driven down as the excavating proceeds. It is not practicable to drive sheathing which is more than 10 to 16 ft. long; so for excavations deeper than this it is necessary to drive a second set of sheathing a few inches inside of the first, and so on, until the required depth is reached, as shown in Fig. 14*b*. This method is not used to any extent at the present time principally on account of the decreasing area of the section as the depth increases.

The decreasing section provided by the method described in the last paragraph may be avoided by sloping the sheathing outward sufficiently to permit the driving of the next set without decreasing the section. This method is illustrated in Fig. 14*c*. The outward inclination of the sheathing creates an objectionable condition at the corners which makes this method unsatisfactory in material such as loose sand, for it is difficult to keep this material from running through at the corners.

**Poling Board Method.** — In material such as clay, which will stand well, vertical sheathing may be placed in short lengths of 4 or 5 ft. as the excavation proceeds, as shown in Fig. 14*d* instead of driving the sheathing as described in the previous paragraphs. Wells excavated in this manner are usually circular. In starting a well the first 4 or 5 ft. of depth is excavated and a set of sheathing is placed, the boards being held in place by metal rings placed inside, forcing the sheathing against the earth which must be accurately excavated if good results are to be secured. After the first set is in place another 4- or 5-ft. section is excavated, another set of sheathing is placed, and this process is repeated until the desired depth is reached. If difficult material is encountered the sections may be as short as 18 in. or 2 ft. The earth is excavated by pick and shovel or the pneumatic spade may be used. The pneumatic spade operates on the same principle as the air drill but the drill is replaced with a spade. As the handle of the spade is pushed, the spade is driven into the earth by compressed air. The earth is hoisted to the surface in buckets by hand or power. A tripod supporting a sheave wheel is placed over the well for convenience in hoisting.

The sheathing is 2 in. or 3 in. tongue-and-groove lumber beveled to fit the curve and the rings vary in size from 3 in. by $\frac{3}{4}$ in. to 4 in. by 1 in. The rings are divided into semicircles with flanges at the ends so that they may be bolted together in pairs, to form the complete circle. In the

wells for the Cleveland Union Terminal Building some of the clay swelled after exposure to the atmosphere and threatened to collapse the lining. This was prevented by inserting, where necessary, heavy wooden drums

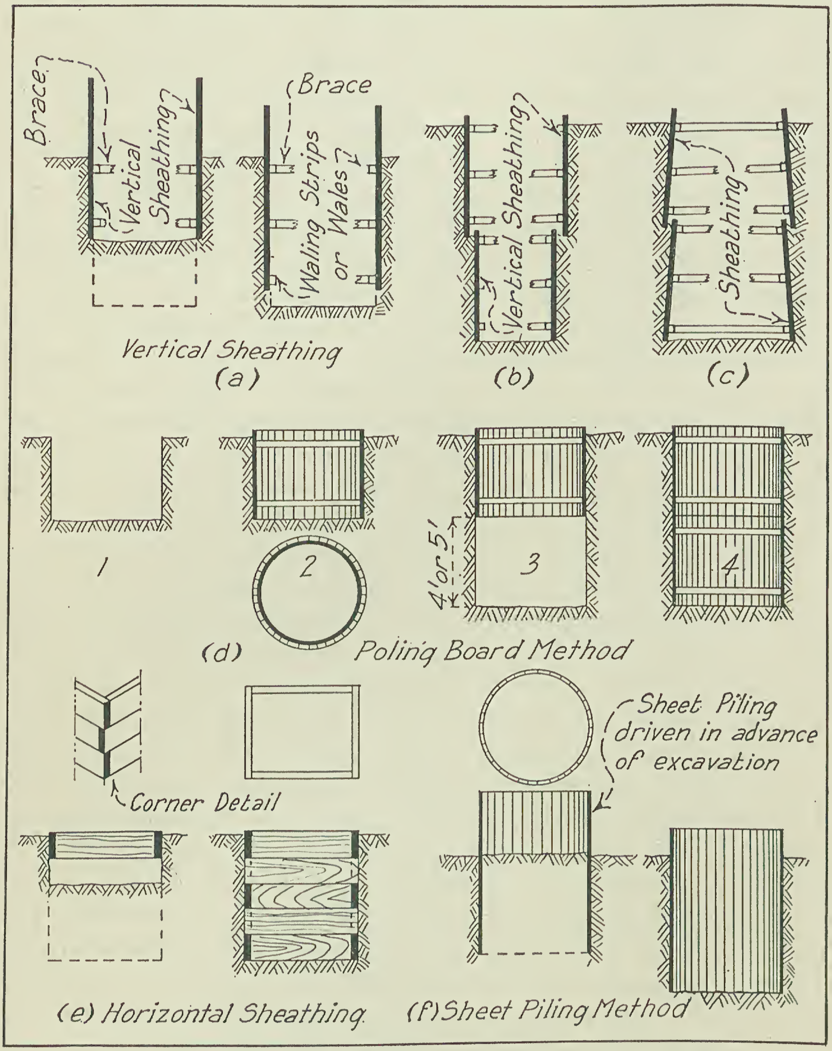



Fig. 14. Horizontal and Vertical Sheathing for Open Wells

divided into two segments which were forced against the lining by jack screws. These drums were removed as the wells were filled with concrete. See Fig. 20.

When using this method for excavations carried below the groundwater level some pumping will usually be necessary, for water will enter

through seams in the otherwise impervious clay. This water is removed by pumping. It is necessary to supply fresh air to the men who are working in the wells. If pneumatic spades are being used the exhaust may be sufficient for this purpose but frequently poisonous and explosive gases are encountered and it becomes necessary to supply a large amount of air by blowers which force the air through air lines extending to the bottom of the wells. See Fig. 20.

This method is commonly called the *Chicago Method* for it is extensively used in Chicago. The sheathing placed by this method is often called a caisson but it is really a cofferdam.

The deepest foundations which have yet been placed were constructed by this method. Sixteen piers for the Cleveland Union Terminal Building were carried to a depth of 262 ft. below the curb and nearly 200 ft. below the ground-water level. A combination of horizontal sheathing, steel sheet piles, and poling boards was used as shown in Fig. 20.

**Horizontal Sheathing.** — Instead of placing the boards vertically as in the method just described, they may be placed horizontally as shown in Fig. 14*e* and Fig. 20, the wells excavated in this manner being square or rectangular in section. In this case the excavation need only be carried a few inches below the last set of sheathing to provide room for the next set, so the method is applicable to soils which would not stand if a considerable depth were exposed. The sheathing usually consists of 2 × 8-in. or 2 × 10-in. planks, called *curb planks*, placed on edge, but in difficult material the width may be 6 in. or even 4 in. Reinforced steel sheets may be used instead of planks. The earth is excavated with pick and shovel or by pneumatic shovels and is hoisted in buckets operated by hand or power.

**Sheet Piling.** — Instead of supporting the earth with sheathing as in the methods just described, sheet piling may be driven around the perimeter of a well in advance of the excavation, as shown in Fig. 14*f*. The enclosed earth is commonly removed by pick and shovel or by pneumatic shovels and is hoisted in buckets. If driving is easy the sheet piling may be driven its entire length before the excavation is commenced but in all cases the piles are kept well in advance of the excavation. The piles are braced by horizontal frames placed as soon as the progress of the excavation will permit.

Sheet piling may be made of wood, steel, or reinforced concrete, the latter not being used in constructing wells for piers. The simplest form of wood sheet piling consists of wood planks driven side by side as shown in Fig. 15*a*. This type will hold back earth but will not keep out water. The most common form of wood sheet piling is the Wakefield piling illustrated in Fig. 15*b*, consisting of three planks spiked together to form

a tongue and groove. Other forms of wood sheet piling are shown in Fig. 15*c*. With the exception of the simple planks all of the forms are intended to keep out water as well as hold back earth. Various forms of steel piling are shown in Fig. 15*d*. If wood piling is used the well should preferably be square or rectangular in section, as shown in Fig. 16*a*, but if steel piling is used a circular section gives good results.

Wakefield piling will stand the impact of drop hammers but steel sheet piling is usually driven with steam or air hammers. Wood sheet piling is sometimes driven with heavy wood mauls.

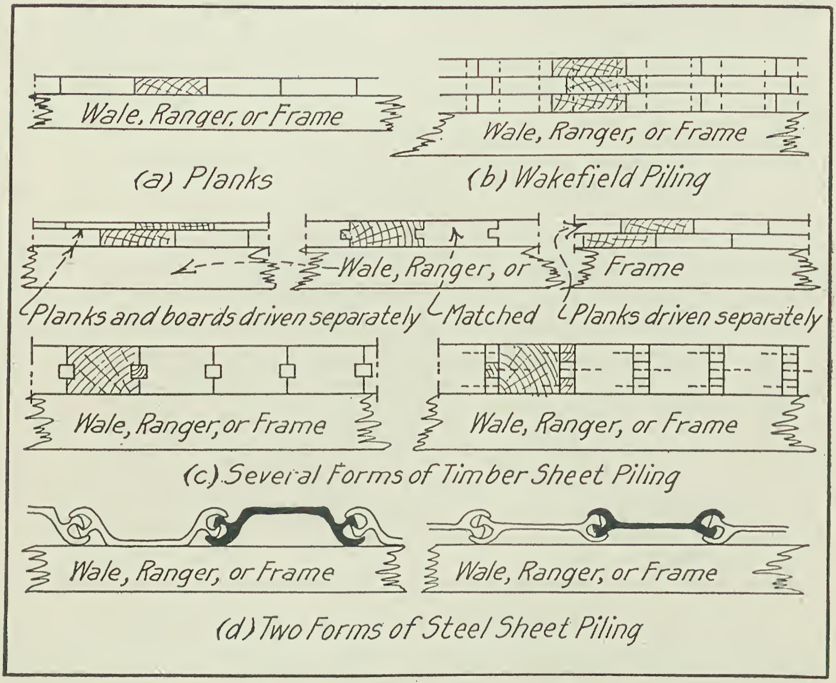



Fig. 15. Types of Sheet Piling

For wells over 20 or 25 ft. deep it is necessary to employ two or more sections of piles offset as shown in Fig. 16*b*, the second section being driven a few inches inside of the first section after the excavation has been completed to a point near the bottom of the first section, and so on for other sections.

This method has been used for wells up to 60 ft. in depth and, if some form of water-tight piling is used, it is applicable for use in digging wells below the ground-water level if the amount of water which enters the excavation is not too great to be removed by pumping or not great enough to wash an excessive amount of the material surrounding the piling under

the piling into the well. Frequently the piles are driven through porous water-bearing material until the ends of the piles are embedded in clay. The clay effectively seals the bottom of the excavation so that water cannot enter.

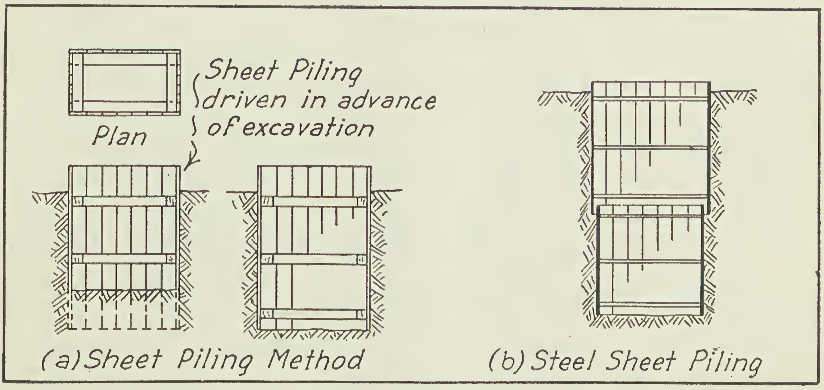



FIG. 16. Use of Sheet Piling

**Telescoping Steel Cylinders.** — Telescoping steel cylinders from 5 to 8 ft. in length may be used in place of vertical sheathing or sheet piling. These cylinders differ in size by 2-in. increments. The largest cylinder is sunk first as shown in (1) Fig. 17*a*, by excavating below the cutting edge and driving the cylinder down. The excavation is carried on by hand methods. After the first cylinder is in position, the second is sunk in the same manner and others in succession until the desired depth is reached, as shown in (2) Fig. 17*a*.[1] A bell, as shown in (2), is excavated at the bottom if the soil permits. After the excavation is completed the space is filled with concrete, as shown in (3), the cylinders being withdrawn as the concrete is placed until the completed pier, as shown in (4), is formed. The waste of concrete due to the decreasing section may be avoided by using a small sized cylinder as a concrete form for the entire depth, the space between the concrete and the outer lining being filled with sand. Telescoping cylinders can be used in water-bearing soils where the material will not hold its shape as required by the poling board method, the cylinders being driven well in advance of the excavating to keep the surrounding soil from flowing into the excavation. A bell cannot be formed unless the final excavation is in a suitable material such as clay. This is one form of the Gow pile and might be classed as an open caisson.

[1] Concrete Piles and Piling Construction, by M. M. Upson. *Proceedings* of Engineering Society of Western Pennsylvania, Vol. 40, p. 119.

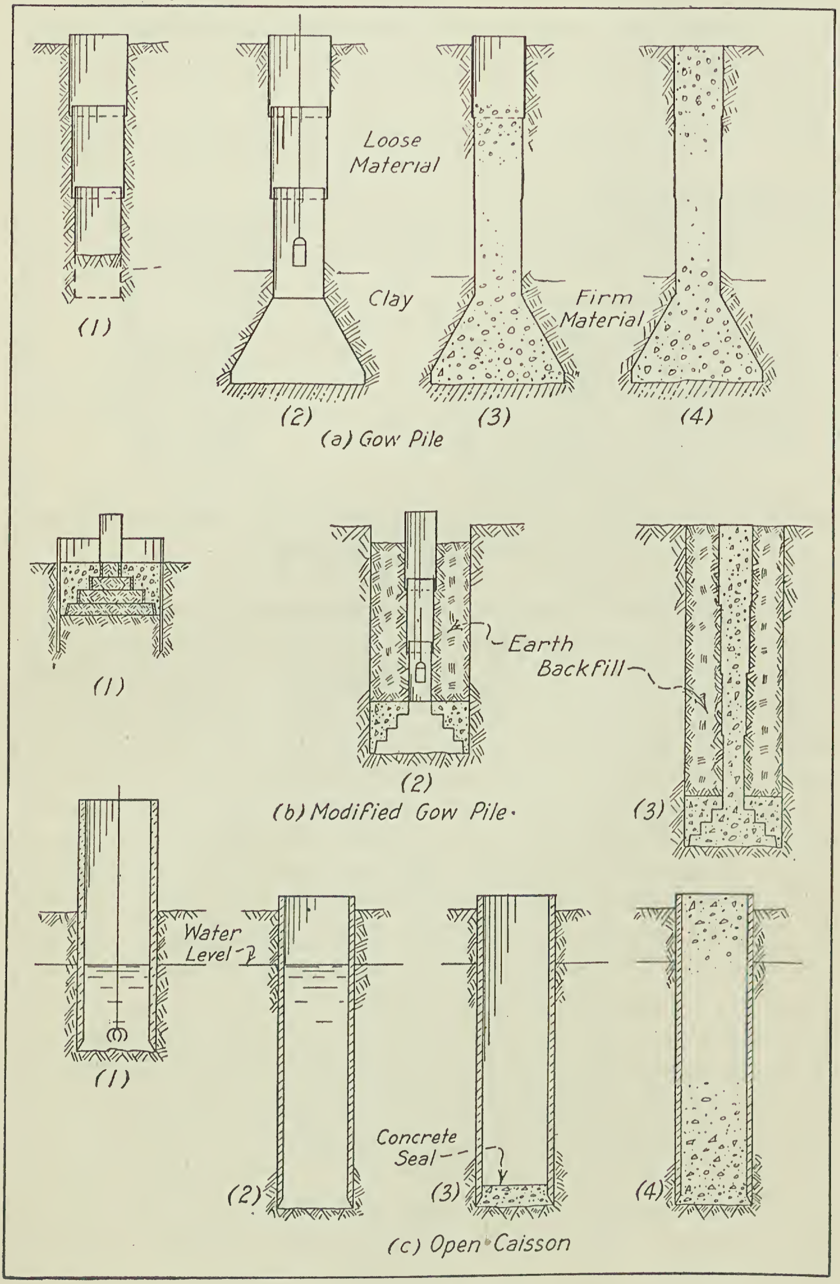



FIG. 17. Gow Piles and Open Caissons

Another form of the Gow pile has been devised for use when the enlarged base is desired and the soil will not permit the base to be belled out as in the type which has just been described. In this type a working chamber forming the enlarged base, as shown in (1) Fig. 17*b*, is constructed of concrete in a properly shaped excavation. The earth in the working chamber is excavated by hand and as the excavation proceeds the working chamber sinks.

A shaft consisting of telescoping steel cylinders, as in the other form of Gow pile, is used to provide a passage from the working chamber to the surface. The earth which is excavated is used for backfilling between the shaft and the surface over which the sides of the working chamber moved, as shown in (2). This earth rests on the top of the working chamber and provides the weight which forces it down as the excavation proceeds.

When a suitable foundation bed is reached the working chamber and shaft are filled with concrete, as in (3). This forms a pier with an enlarged base for use on soils with a relatively low bearing pressure as compared with the strength of concrete. If a pier is to rest on bedrock of which the bearing power is at least equal to the strength of the concrete in the pier, an enlarged base is not necessary and this method of construction is not suitable. Under these conditions the ordinary form of Gow pile, omitting the bell, can be used if water is not encountered in serious quantities, or some other method such as the poling board method may be suitable. If water is present in large quantities the open caisson or the pneumatic caisson will have to be used. A form of the Gow pile for use in water-bearing soils which require the pneumatic process is described under pneumatic caissons. All forms of the Gow pile are patented.



**Types of Caissons.** — The term caisson is derived from the French word, meaning box. There are three forms of caissons used in constructing foundations, under water, *i.e.*, the box caisson, the open caisson, and the pneumatic caisson.

According to Jacoby & Davis[1] "a caisson is a box; if open at the top and closed at the bottom it is a box caisson; if open both at the top and bottom it is an open caisson; while if it is open at the bottom and closed at the top and utilizes compressed air, it is a pneumatic caisson."

It is sometimes difficult to distinguish between a cofferdam and a caisson. In general, if the structure is self-contained and does not depend upon the surrounding material for support, it is a caisson, but if it requires such support, as in the case of sheathing, poling boards, and sheet piling, it is a cofferdam.

[1] Foundations for Bridges and Buildings (McGraw-Hill Book Co).

**Box Caissons.** — Box caissons are used in constructing bridge foundations under water, where no excavation is required except preparing the site to give good bearing for the caisson. The caisson, which may be constructed of timber, reinforced concrete or steel, is towed into position, filled with concrete or stone masonry and sunk until it rests on the river bottom which has been prepared to receive it, or on a pile cluster, to form the lower part of a bridge pier. Box caissons are not applicable to foundations for buildings.

**Open Caissons.** — Open caissons are sometimes used for constructing building foundations where the excavation is to be carried on below the ground-water level. They may be constructed of steel or of reinforced concrete. The lower part of the caisson is assembled over the site of the pier. Earth is removed through the water by orange-peel buckets operating through the open space inside of the caisson walls. As the earth is excavated the caisson sinks, due to its own weight, or is forced down by adding weights. Additional sections are added at the top as the sinking progresses. When the caisson reaches its final position and the earth has been removed from the inside, the caisson is filled with concrete placed through the water in the caisson by means of drop-bottom buckets, or a layer of concrete is placed at the bottom of the caisson and allowed to harden forming a seal. The water is then pumped out and the remainder of the concrete is placed "in the dry." This process is illustrated in Fig. 17*c*. The depth to which excavations may be carried by means of open caissons is limited only by the friction on the sides of the caisson which may become so great that the caisson can not be forced down at a reasonable cost. Water jets are sometimes used along the sides of the caisson to reduce the friction. The open caisson has been used for an excavation over 250 ft. deep.

The open caisson is commonly used for the foundations of buildings carried to a considerable depth below the ground-water level to reach a satisfactory bearing material. While excavating, a large amount of the surrounding material flows under the caisson and has to be removed. If the caisson passes through quicksand the amount of material which runs in may be quite large, but clay runs in very little. It is evident that this material which runs in an open caisson may cause the foundations of nearby buildings to be undermined. This may prohibit the use of the open caisson, in which case the pneumatic caisson may be used even though the cost is greater.

The open-caisson method does not permit the examination of the material on which the pier is to rest and it is not possible to prepare the bearing surface to receive the pier. For these reasons, provision is sometimes made for the conversion of an open caisson into a pneumatic

caisson after the foundation bed is reached so that the bed may be examined and prepared to receive the pier. Using this combined method the economy of the open caisson is taken advantage of for most of the excavation but the pneumatic process used at the end assures a good foundation.

The foundations for the Lincoln Memorial in Washington, D. C., consist of concrete piers carried to bedrock by the open-caisson method using steel cylinder caissons. The caissons varied in diameter from 3 ft. 6 in. to 4 ft. 2 in. and in length from 42 ft. to 56 ft. The lower 20 ft. was constructed of $\frac{1}{2}$-in. plate and the remainder of $\frac{3}{4}$-in. plate. The ground-water level was 16 ft. below the surface. To start each cylinder a hole 10 or 12 ft. deep was dug and provided with frames for plumbing the cylinder. A 20-ft. section of the cylinder was placed vertically in the frames and loaded with from 10 to 20 tons of concrete blocks placed on the upper edge. This weight, with the aid of a water jet, forced the cylinder down. When it ceased to sink, the interior was excavated with an orange-peel bucket. The weight was again applied and the process continued until bedrock was reached. The cylinder was lengthened when required as the sinking progressed. The material through which the caissons penetrated is mostly an imprevious clay so the leakage was slight. After the cylinders had reached bedrock they were filled with concrete reinforced with vertical steel rods held in place by spirals with a one-foot pitch.[1]

Steel cylinders are sometimes driven with steam hammers.

**Pneumatic Caissons.** — Pneumatic caissons are extensively used for constructing building foundations which consist of piers carried through water-bearing material to bedrock. The essential parts of a pneumatic caisson are the working chamber, the shaft, and the air locks as shown in Fig. 18*b*. The working chamber may be constructed of timber, steel, or reinforced concrete. The shaft is usually constructed of steel.

The pneumatic caisson process is illustrated in Fig. 18*a*. The lower end of the caisson including the working chamber is first constructed and placed on the surface of the ground or in a hole excavated to receive it, as shown in (1). Excavation is carried on in the working chamber and the caisson sinks due to its own weight or it may be necessary to place a load on it. As soon as the ground-water level is passed by the cutting edge water begins to rise in the working chamber; therefore the air locks are placed at the upper end of the shaft as shown in (2) and sufficient air pressure is applied to the working chamber to force the water out. Men can now work in the working chamber without the interference of water.

[1] *Engineering News-Record,* Vol. 71, p. 1019.

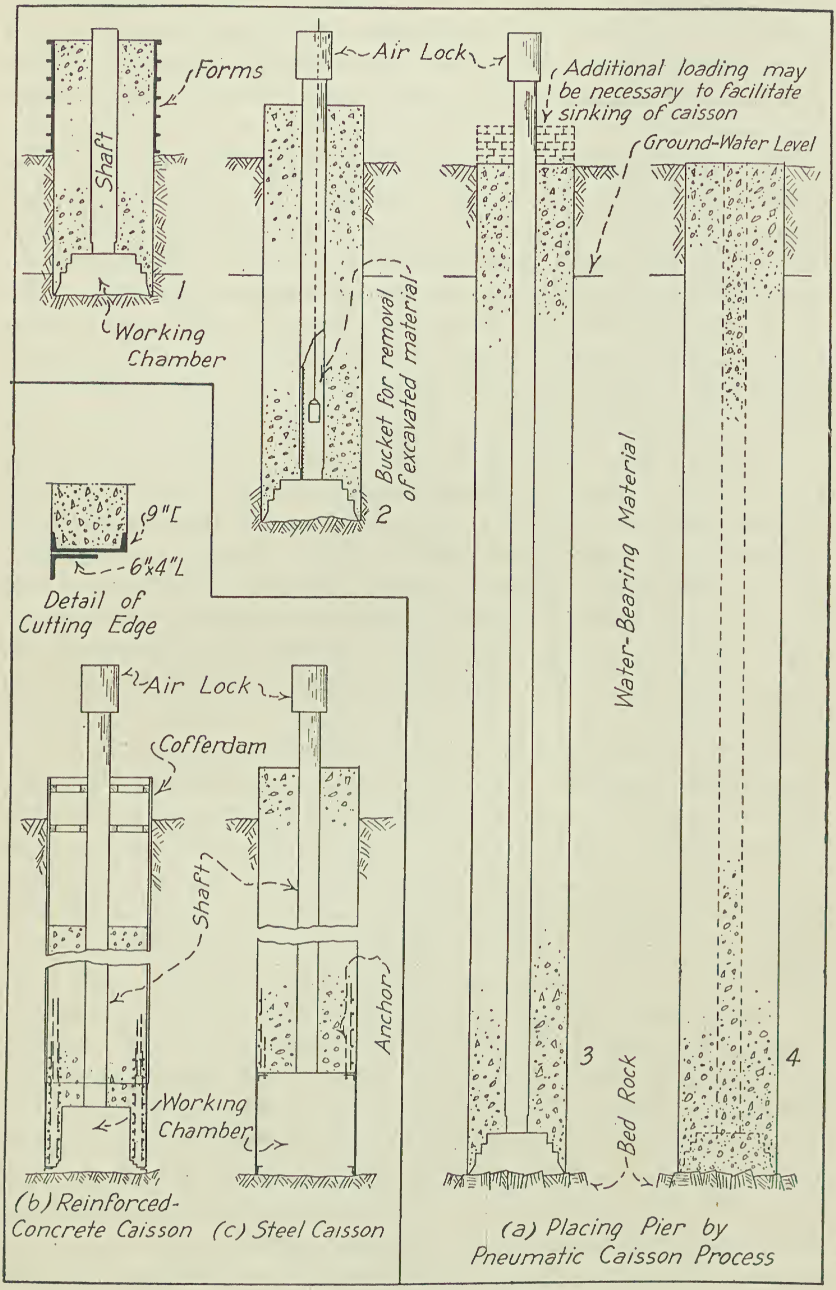



Fig. 18. Pneumatic Caissons

As the caisson sinks the pressure in the working chamber must be increased to balance the water pressure.

The part of the caisson above the working chamber may be surrounded with a timber cofferdam as shown in Fig. 18*b*, to hold back the earth and water as the caisson sinks. Concrete is placed in the cofferdam to form a part of the pier and to serve as a weight to assist in forcing the caisson down. Removable forms may be used instead of the cofferdams, as shown in Fig. 18*c*, in which case the top of the concrete is always kept well above the top of the ground. The latter procedure provides more weight for forcing the caisson down but the friction of the concrete against the earth is greater than the friction of the timber cofferdams and so more weight is necessary. Frequently the entire pier as required by the depth from the surface to rock is completed before the sinking starts.

The earth exposed in the working chamber is excavated by any convenient method such as pick and shovel or air spade and is hoisted to the surface in buckets through the air locks. If the material is quite fluid it may be disposed of by blowing it to the surface through a pipe, the air in the working chamber providing the necessary pressure. Spoil which is to be blown out is heaped over the end of a stiff hose placed on the bottom of the working chamber and connected to the pipe leading to the surface. A valve is provided so that this pipe may be closed when not in operation.

When the cutting edge of the caisson has reached bedrock the surface of the rock is prepared to support the pier. A layer of concrete thick enough to resist the hydrostatic pressure is placed in the bottom of the working chamber and allowed to set. This seals the caisson so that water cannot enter. The air pressure is released, the air locks and possibly the shaft are removed and concrete is carefully placed under atmospheric pressure in the remaining portion of the working chamber and the shaft. Care must be exercised to avoid air pockets and to overcome the effect of the shrinkage which occurs in the concrete while setting.

A form of the Gow pile has been devised for use where pneumatic methods are desirable. The working chamber is constructed as in (1) Fig. 17*b* but an airtight concrete shaft is used in place of the telescoping steel shaft which would not be airtight. Air locks are placed on the shaft, compressed air is forced into the working chamber and the process continues as in the usual type of pneumatic caissons. This type of pier is suitable for use when the foundation bed is a firm material such as hardpan the bearing power of which is less than the strength of concrete, thus requiring the bearing area to be larger than the cross-section of the

shaft. The enlarged base is not required if a pier rests on bedrock since the bearing strength of bedrock is usually much greater than the strength of concrete.

The advantages of the pneumatic process are as follows: When properly operated, the only excavation required is that represented by the volume occupied by the pier, so adjacent foundations are not undermined as may be the case in the open-caisson process. An opportunity is afforded to examine and properly prepare the foundation bed to receive the pier. This is not possible in the open-caisson process.

The disadvantages are: The limitation of the depth below the groundwater level to about 110 ft. because men cannot safely work in the air pressure required by greater depths. (This depth requires a pressure of about 50 lb. per sq. in.) and the high cost as compared with the open-caisson method.

The pneumatic-caisson process is very extensively used in constructing the foundations for tall buildings, especially in New York City.

**Caisson Cofferdams.** — Large buildings are often constructed with two or three floors below the ground level and in some cases as many as five such floors have been provided. The excavation above the groundwater level is carried on by supporting the banks with vertical sheathing or piles in the usual manner. Where floors are located below the groundwater level it is necessary to provide watertight exterior walls.

The walls are commonly constructed by the pneumatic-caisson method and consist of a cofferdam of rectangular reinforced-concrete caissons from 5 to 8 ft. wide and 30 ft. or more in length as shown in Fig. 19. Each caisson is preferably poured in one operation before sinking. In this way horizontal joints are avoided and a more watertight caisson is secured. Each caisson is sunk until the cutting edge strikes bedrock. The space between the irregular surface and the cutting edge is filled in by underpinning with concrete to secure a watertight joint. The working chamber is then filled with concrete as described under "Pneumatic Caissons." The small pipe in the roof of the working chamber, shown in the figure, is a vent to permit air to escape and avoid air pockets when the working chamber is filled, the seal having already been placed.

Many methods have been devised for making the joints between the caissons watertight. One of the most recent and simplest methods was devised by T. Kennard Thompson[1] and is shown in the figure.

The ends of adjacent caissons are kept 6 in. apart by two 6 × 8-in. oak timbers bolted vertically to the caisson which is sunk first. These timbers are 3 ft. apart. After the caissons are in place a 4-in. pipe is jetted down to the cutting edge in the space between the timbers. The

[1] *Engineering News-Record*, Vol. 88, p. 914.

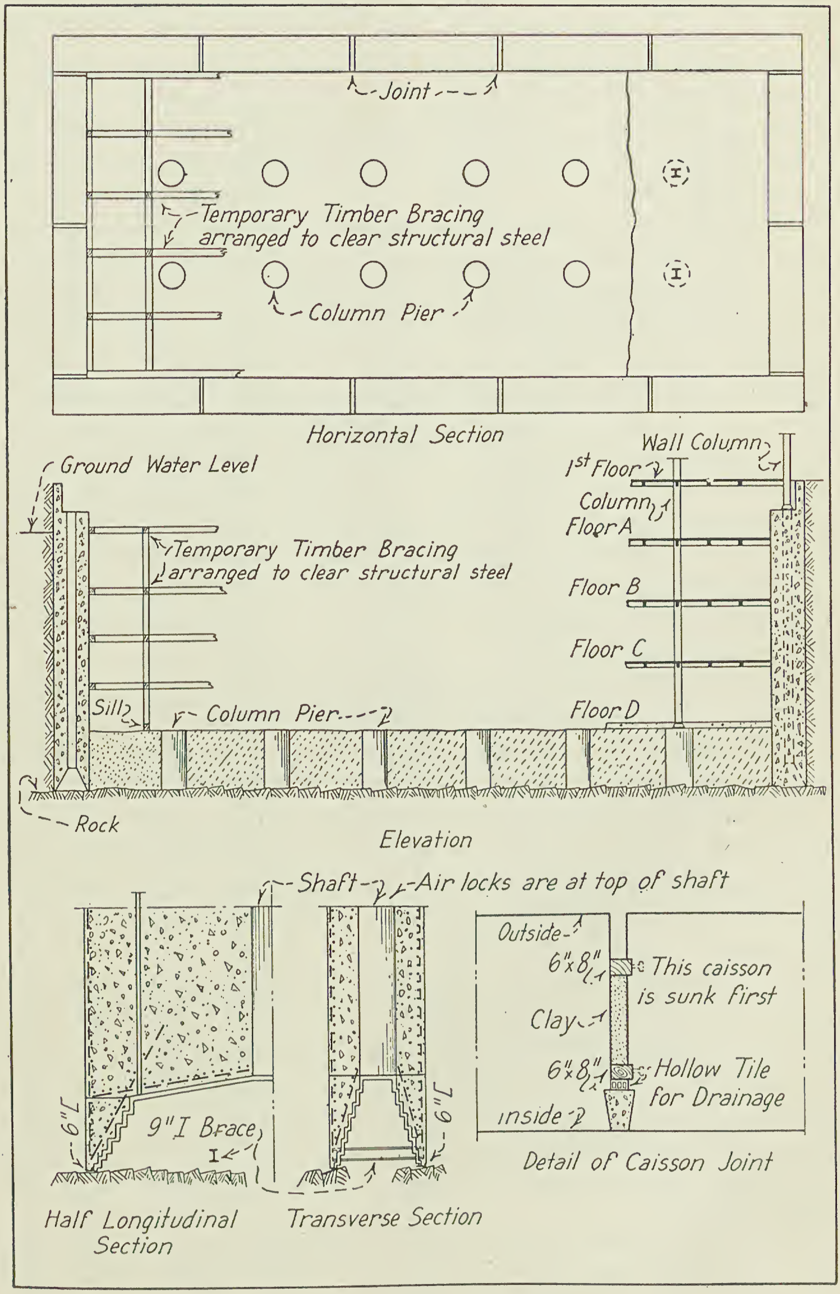



Fig. 19. Caisson Cofferdams

sand is washed out of this pipe and slugs of clay are dropped down into the pipe. The clay is forced out of the bottom of the pipe by a ramrod struck lightly with the piledriver when necessary. The pipe is gradually raised as the joint becomes filled until the seal is completed to the top. If the clay is rammed too tightly the caissons may be forced apart. The remainder of the joint is placed after the excavation is completed, as will be explained later.

After all of the caissons are in position and the clay seals are completed, the earth inside of the cofferdam is removed to the desired depth. While this is being done it is usually necessary to provide temporary bracing to keep the caisson from being forced inward by the surrounding earth and water. This may be in the form of *cross-lot bracing* consisting of timber struts extending both ways from wall to wall and supported vertically at the intersections, or horizontal trusses may be used to provide more clear working space.[1] This bracing is placed as the excavation progresses and must be so arranged as to clear the structural frame which, when placed, takes the place of the temporary bracing. When possible, the floor construction is designed to provide adequate lateral support but due to the open spaces necessary in the floors for elevators and other equipment, special bracing may be required. In order to prevent the moving of the caissons due to the deformation of the timber bracing it is necessary to put initial compression in the struts by means of wedges. Frequently the structural steel framing for the floors is so designed and detailed that it can be placed before the columns and thereby take the place of the temporary bracing with a resultant saving in cost.

When the excavation has been completed the dove-tailed grooves at the caisson joints are cleaned out and filled with concrete. The hollow tile shown in the figure is provided to catch any water which penetrates the clay seal. This water is led to a sump and is disposed of by pumping.

Even though the walls are watertight and a watertight joint is secured between the caissons and bedrock, it is quite probable that water will work its way into the lower floor through fissures in the rock. By placing crushed rock or a system of drains under the lower floor this water may be drained to a sump where it is easily disposed of by pumping into the sewers. If a watertight membrane is used under the floor instead of using drains, the floor must be designed to resist the uplift due to hydrostatic pressure.

If the lower floor is placed above the elevation of bedrock, the wells for the interior piers can be excavated without serious interference by water.

[1] *Engineering News-Record,* Vol. 88, p. 914.

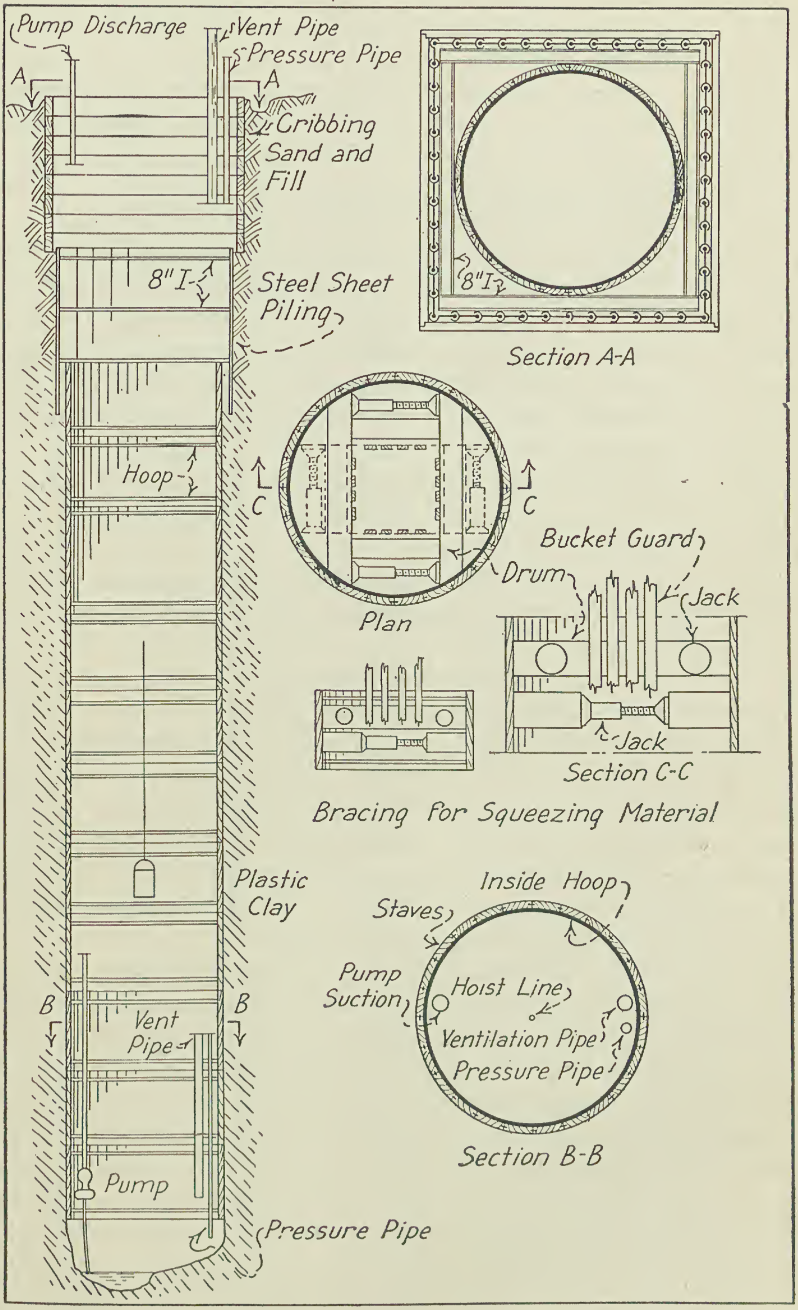



FIG. 20. Foundation for Cleveland Union Terminal Building

**Combined Methods.** — It is frequently not feasable to use one method for the construction of the entire depth of a well, and two or more methods may be combined.

If a stratum of water-bearing material such as water-bearing gravel or quicksand lies on top of a thick stratum of clay which is underlain with hardpan or rock, sheet piling may be driven through the quicksand into the clay a sufficient distance to form a watertight seal and the remainder of the depth may then be excavated by the poling board method.

At the site of the Cleveland Union Terminal Building this condition existed but the ground-water level was a few feet below the level at which the excavation for the well was started. The upper part of the well down to the ground-water level made use of horizontal sheathing as shown in Fig. 20. Below this, and extending to the surface of the clay, steel sheet piles were used and the remaining distance was excavated by the poling board method:

When a stratum of water-bearing gravel or quicksand lies between a top stratum of clay and bedrock, the poling board method may be used until the clay is nearly penetrated. From this level, steel sheet piles may be used to reach bedrock. In order to avoid a reduction in section the well may be belled out in the clay for a sufficient height to permit the driving of the piles.

On account of their relatively low cost, open caissons may be used to penetrate a water-bearing stratum of sand, gravel or silt but they may be so arranged that locks may be placed on top of the dredging wells to convert them into pneumatic caissons. This procedure may be adopted as a precaution in case material which the open caisson will not penetrate may be encountered or it may be considered desirable to secure the advantages of the pneumatic-caisson method in preparing the foundation bed and in filling the caisson with concrete. Open caissons are used very little in constructing foundations for buildings.

Many other combinations might be cited to meet varying conditions but those which have been mentioned will serve as general illustrations.

**Well-point Method.** — The well-point method for excavation in water-bearing material consists of surrounding the area to be excavated by a row of closely-spaced well-points placed along each side and lowering the water table in that area by pumping the water through the well-points. The excavation within the area can then be carried on in the dry. A well-point is a pipe provided with a point at its lower end and with a screen or filter along the lower 3 or 4 ft. of its length. Some types are designed for driving with a maul while others are jetted into position. The well-points are set about 3 ft. apart, the top of each point being connected to a header pipe which is connected to a pump. The water-

level may be lowered as much as 20 or 30 ft. This method is used chiefly in trench excavation and in unwatering the whole area occupied by a building but is also applicable to excavation for piers. It is usually necessary to provide sheathing to keep the banks from caving, but this does not need to be watertight.

## ARTICLE 15. DRAINAGE OF FOUNDATIONS

The foundations of buildings are frequently provided with drainage systems to carry off ground-water which may reduce the bearing power of the soil or tend to cause damp or wet basements. These drainage systems may consist simply of a backfilling of loose rock to collect water which would otherwise come against the wall, and which is provided with an outlet so that water collected may drain away into a separate drainage line or into a sewer, if permitted. The top foot or so of the backfilling is made of ordinary soil to permit planting and to keep surface water from entering the rock backfill. This type of drainage system is illustrated in Fig. 21*a*. Instead of relying on the rock drain just described to carry the water away, a line of sewer pipe laid with open joints is commonly installed next to the footings as shown in Fig. 21*b*, or a drain consisting of a half tile on a concrete slab, as shown in Fig. 21*c*, can be used.

In the systems which have been described there will usually be some water standing in the bottom of the trench which may decrease the bearing power of the soil. A more effective system consists of installing a drainage system in trenches located a few feet outside of the area occupied by the building. These trenches are carried down well below the bottom of the footings and may surround the building, or in case of underground water having a definite direction of flow the trenches may often be necessary only on the upstream side of the building and the two adjacent sides, omitting the trench on the downstream side. These trenches are filled with rock and may be provided with a drain or sewer pipe laid with open joints, or in some cases, the loose rock with which the trenches are filled is depended upon entirely to carry the water away. These systems are illustrated in Fig. 21*d*. The loose rock fill effectively cuts off all water from the building and the drain carries it away. The top 18 in. or 2 ft. of the trenches is filled with ordinary soil to keep surface water out of the trenches and to support vegetation.

Often ground-water is present in a porous layer of gravel under which there is a layer of impervious clay as shown in Fig. 21*e*. Even though the foundations go well down into the clay it may not be necessary to carry the drainage trenches to that depth. Under these conditions trenches

carried down about a foot into the clay as shown in the figure, have effectively cut off all underground water. Seams of porous material in the clay may prevent this type of installation.

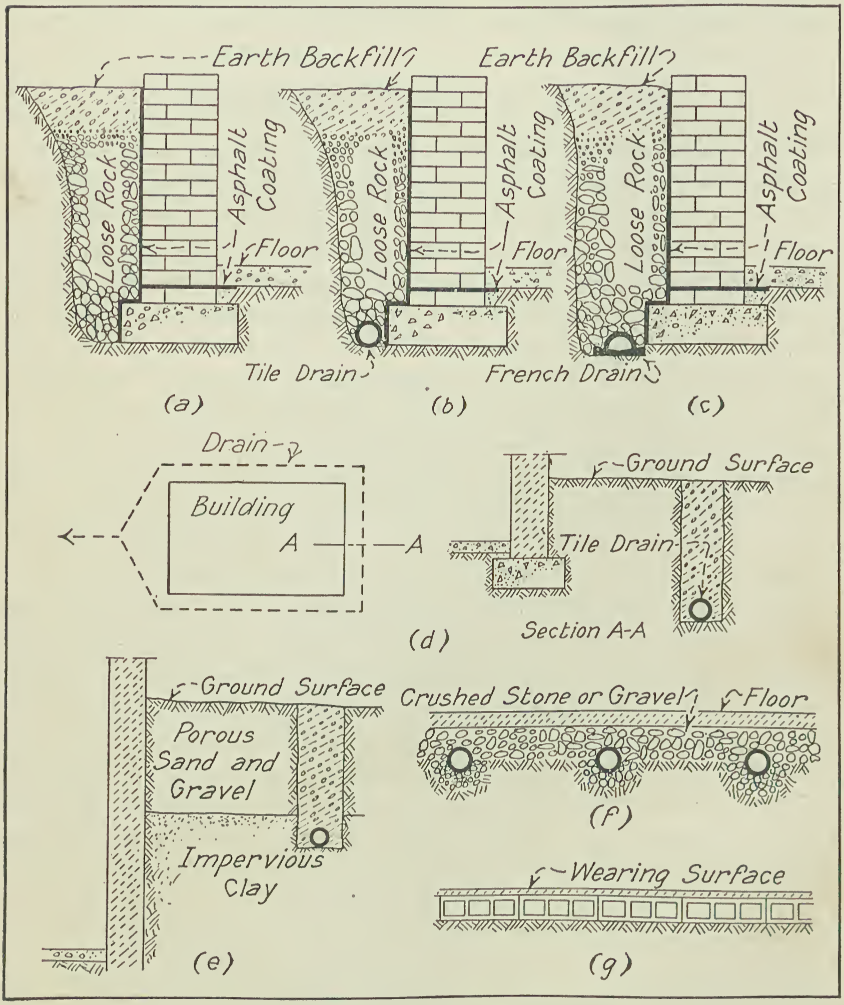



Fig. 21. Drainage of Foundations

Basements are sometimes drained by a system of drains placed under the floor in a layer of crushed rock, gravel, or cinders as shown in Fig. 21*f*. This system does not prevent water from soaking through the outside walls and is less effective than the methods just described. If an effective drainage system is placed outside of the building this interior drainage is unnecessary except where springs exist inside of the building area.

In some cases a system of drainage for floors has been formed by placing a layer of hard-burned hollow tile under the floor and providing a wearing surface on the tile of cement mortar an inch or more in thickness. These tile are connected to a drain which conveys the water away. This method is illustrated in Fig. 21*g*.

In all of the methods which have been described it is necessary to dispose of the water collected in the drainage system by connecting the system to one or more drains which convey the water away to nearby streams, ravines, or low-lying ground. Frequently the drains may be connected to the city sewer systems.

In some cases where the amount of water is small and it is impossible to convey it away by gravity, the water may be collected in a *sump* from which it is pumped. Where the amount of water is large and can not be disposed of by gravity drainage, it is usually necessary to waterproof the basement to keep the water out, and permit the building to stand in water. Frequently the lowest basement floor level is 20 or 30 ft. below the ground-water level. Under these conditions, it may be necessary to waterproof the foundation walls and the basement floor. The pressure of water must be considered in design. The methods used in waterproofing are described in Article 16.

The use of watertight caisson cofferdams is described in Article 14 and illustrated in Fig. 19.

Surface water may find its way into basements when the backfilling against the walls has been carelessly done. As a rule, this difficulty can be overcome by carefully tamping a layer of clay a few inches thick on the surface around the building. This layer should be 3 or 4 ft. wide. In extreme cases, it may be desirable to backfill entirely with clay well tamped in place.

## ARTICLE 16. WATERPROOFING OF FOUNDATIONS

Where foundation walls are below the ground-water level or where an underground flow is encountered, a basement may be kept dry by an effective drainage system as described in Article 15, or if this is impracticable the foundation walls and floor must be waterproofed.

Frequently, the amount of water which comes in contact with the foundation walls is small but still the basement is damp. Under these conditions the walls may be damp-proofed at a much lower cost than that of waterproofing.

Since foundation walls are usually made of concrete the waterproofing of this material will be considered first.

**Watertight Concrete.** — By a proper selection of aggregates, the use of a sufficient amount of cement, and avoiding excess water, concrete may

be made watertight if carefully placed to avoid honeycombed or porous spots due to segregation of the aggregates. Any possibility of the formation of cracks must be guarded against and construction joints must be carefully made, for even if the concrete itself is impervious any joints which are not watertight or any cracks will, of course, make it ineffective in keeping out water.

The laitance which forms on top of concrete at the end of a run is a fruitful source of leaks in concrete walls. The surrounding water seeps through the planes formed by the laitance causing cracks which gradually increase in size. The 1924 Joint Committee Report contains the following requirement:

> Where construction joints are required to be watertight the method of construction shall be as follows:
>
> (*a*) Horizontal joints shall be constructed by forming a continuous keyway in the lower portion of concrete before the concrete has hardened. Before placing the superimposed concrete, the joint shall be thoroughly cleaned of laitance or other foreign material, saturated with water, and coated with neat cement grout. The superimposed concrete shall be placed in such a manner as to insure an excess of mortar over the entire surface of the joint.
>
> (*b*) Vertical joints shall be made by a metal waterstop approved by the Engineer.

The construction of watertight walls by means of caisson cofferdams is described in Article 14.

**Methods of Waterproofing.** — Many other methods are used for making concrete watertight but they may all be grouped under three heads:

1. Integral Method.
2. Surface Treatment Method.
3. Membrane Method.

**Integral Method.** — The integral method of waterproofing concrete consists of adding certain substances to the concrete to act as void fillers and thereby prevent the passage of water through the concrete. These substances may be in the form of a powder added to the cement at the building site or at the manufacturing plant, or they may be in the form of pastes or liquids added to the mixing water or simply mixed in with the other materials going into the concrete.

Some of the materials used in integral waterproofing are finely-ground clay or sand, hydrated lime, chloride of lime, oil emulsions, and lime soaps. Clay, sand, and hydrated lime are classed as inert fillers while the other substances react with the cement to form other compounds which are often water-repellant in nature. Many of the integral waterproofing materials are patented or have their compositions kept secret.

Integral waterproofing materials act primarily as void fillers but some of them, such as hydrated lime, have a lubricating action which assists the materials in sliding into place and thereby forming a more dense and waterproof concrete. The integral method is used during construction and is not applicable to structures already in place. Technologic Paper No. 3 of the U. S. Bureau of Standards, states that:

> The addition of so-called integral waterproofing compounds will not compensate for a lean mixture nor for poor materials, nor for poor workmanship in the fabrication of the concrete, since, in practice, the inert integral compounds (acting simply as voidfilling material) are added in such small quantities that they have little or no effect on the impermeability of the concrete. If the same care is taken in making the concrete impermeable without the addition of waterproofing material, as is ordinarily taken when waterproofing materials are added, an impermeable concrete can be obtained.

Of course, integral waterproofing compounds will not prevent water from flowing through expansion, shrinkage, or settlement cracks, and construction joints. Some integral waterproofing compounds have a detrimental effect on the strength and durability of concrete.

Without doubt, some of the integral waterproofing compounds which are on the market will give good results, but in general this method of waterproofing should be used with caution. The 1924 Joint Committee Report contains the following clause:

> Integral compounds shall not be used for waterproofing unless specifically authorized by the Engineer.

**Surface Treatment.** — Concrete or masonry walls may be waterproofed or damp-proofed by applying an impervious coating to the surface of the walls.

This coating may consist of (1) rich cement mortar with a smooth troweled surface or cement mortar placed with a cement gun; (2) bituminous materials, such as coal tar or asphalt, applied hot or dissolved in some material to form a paint; (3) paraffin applied hot on a heated surface or in solution in some material to form a paint; or (4) soap and alum solutions (Sylvester process), a coating of hot soap solution being followed by a coating of alum both applied with brushes. Many waterproofing compounds for use in surface treatment are on the market, their compositions being covered by patents or being kept secret. Most of them would fall under one of the four heads mentioned above. The cement mortar coating mentioned in this list may be made with ordinary portland cement, waterproof cement, or an integral waterproofing compound and portland cement.

This type of treatment is suitable for waterproofing or damp-proofing structures which are already in place or structures which are under construction. It is cheaper than the integral method or the membrane method but less effective than the membrane method. Cracks which are due to temperature changes, settlement, or construction joints and which develop after the treatment has been applied will, of course, admit water but if damp-proofing only is necessary, the effect of such cracks is not

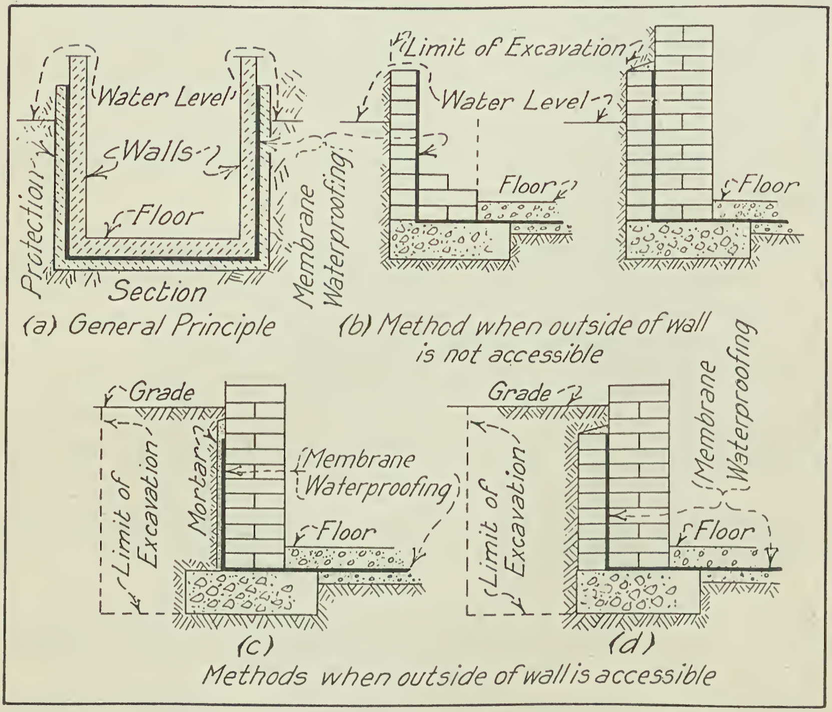



FIG. 22. Waterproofing of Foundations

serious. For the most positive results the coating should be applied to the outside of a wall but good results may also be secured with coatings placed on the inside surface because of the difficulty or impossibility of reaching the outside surface.

For a discussion of colorless waterproofing compounds see Article 19.

**Membrane Method.** — The membrane method of waterproofing consists of surrounding the entire surface, of the part of a building which is below water, with a waterproof membrane as shown diagrammatically in Fig. 22*a*. This membrane consists of a bituminous material which cements together several layers of waterproofing felt, burlap, or canvas. The bituminous material may be coal-tar, pitch, or asphalt applied hot.

The membrane method is applicable to all types of masonry including concrete. See Article 62, for further information concerning bituminous materials.

In order to produce successful results the bituminous membrane must be absolutely continuous around the walls and under the floors. The membrane should be protected against injury by a layer of brick or concrete.

If the basement is not to be excavated far enough outside of the building to permit the membrane to be applied to the walls from the outside, a four-inch wall of brick may be built up outside of the wall line as shown in Fig. 22*b*. The membrane is applied to this wall as shown in the figure, and the wall proper is built against the membrane. If the membrane is applied from the outside it may be protected by a heavy coating of cement mortar as shown in Fig. 22*c* or by a four-inch brick wall as shown in Fig. 22*d*. By referring to Figs. 22*b* to *d* it will be noted that the floors are waterproofed by first placing a thin slab on a porous fill; the membrane is then placed on this slab and a heavier slab is placed on top of the membrane. This top slab must be designed to carry the pressure due to the static head of the water which comes in contact with the floor.

The membrane method of waterproofing is the most reliable of any mentioned in this article. The membrane must be very carefully laid, for leaks are often due to poor workmanship and are very difficult to repair. The membrane, being elastic, will usually not be broken by expansion or settlement cracks.

## REFERENCES

The subject of waterproofing is extensively covered in Waterproofing Engineering by Joseph Ross. (John Wiley & Sons.) Details of waterproof construction for buildings are shown in Good Practice in Construction by Philip G. Knobloch. (Pencil Points Press, 1927.)

# CHAPTER IV

# MASONRY CONSTRUCTION

## ARTICLE 17. DEFINITIONS AND GENERAL DISCUSSION

The walls of a building have many functions. They may be used simply for enclosing the building or parts of the building. They may be required to carry their share of the weight of the buildings and contents, they may carry only their own weight, or they may be carried by the structural frame. They are required to keep out rain, to resist the transmission of heat, and to resist fire. On account of their many functions walls are divided into a large number of classes. The names which are applied to the various classes of walls are not standardized and vary somewhat in different parts of the country. These differences will be noted in the classification given in the next paragraph.

**Classes of Walls.** — Walls are divided into many different classes depending upon their position and functions.

A *bearing wall* is one which supports any vertical load in addition to its own weight.[1]

A *nonbearing wall* is one which supports no load other than its own weight.[1]

A *panel wall* is a nonbearing wall in skeleton construction, built between columns or piers and wholly supported at each story.[1] This type of wall is also called a *filler wall*, a *curtain wall*, and an *enclosure wall.*

An *inclosure wall* is an exterior nonbearing wall in skeleton construction anchored to columns, piers, or floors, but not necessarily built between columns or piers.[1] It may be supported at each story or at intervals of two or more stories, as best suits the design; it is not the same as a panel wall which must be wholly supported at each story.

A *curtain wall* is a nonbearing wall between columns or piers and is not supported by girders or beams.[1] Many building codes apply the term curtain wall to walls of the type indicated in panel wall defined above.

A *spandrel wall* or *spandrel* is usually considered as a panel wall below the windows which fill practically the entire space between columns but some apply this term to the portion of a panel wall between the top of a window and the floor construction above. See Fig. 23*a*.

An *apron wall* is a less common term for a spandrel wall and applies

[1] Recommended Minimum Requirements for Masonry Wall Construction, Building Code Committee, Department of Commerce.

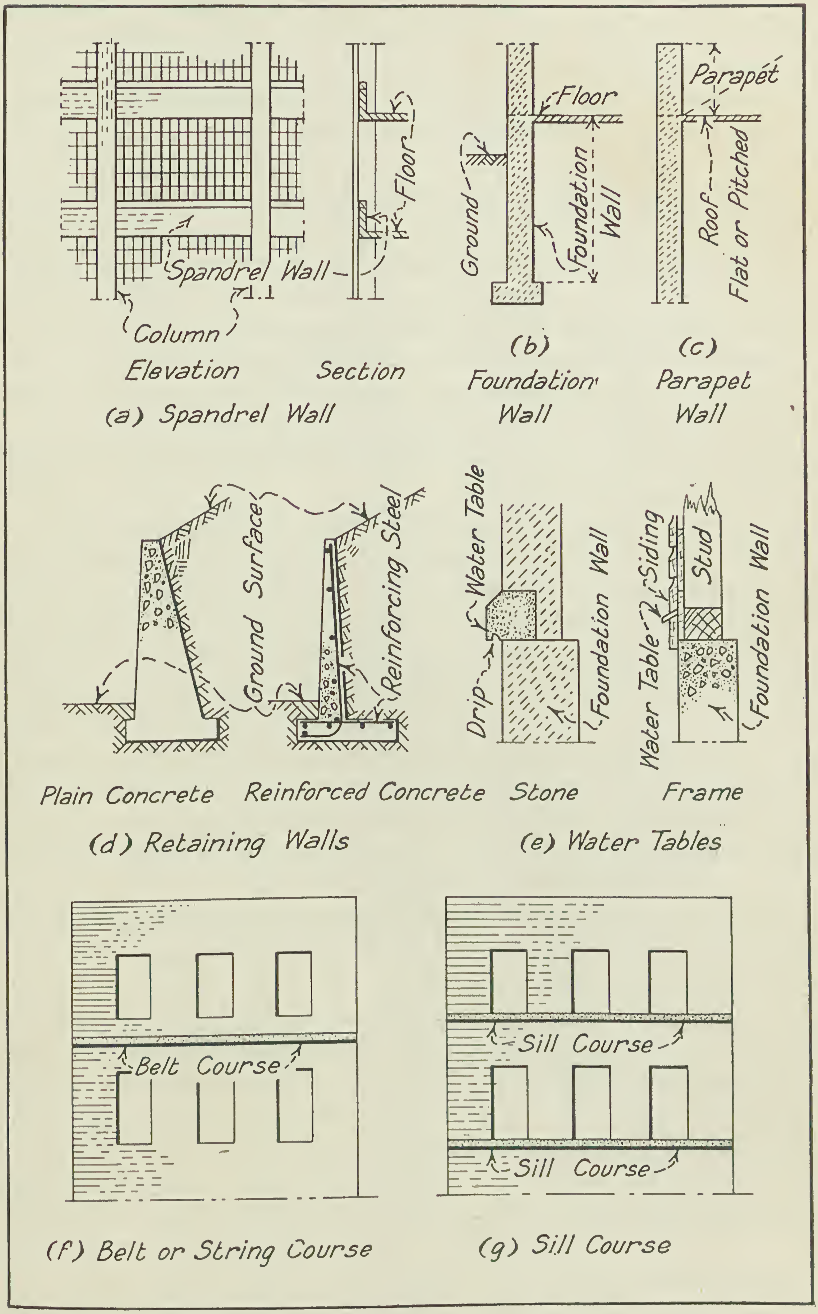



FIG. 23. Parts of a Wall

only to the portion of the wall between the sill and the floor line or, according to some codes, between the head of the windows of one story and sills of the next story.

A *parapet wall* is that portion of any wall which extends above the roof line and bears no load except as it may serve to support a tank.[1] See Fig. 23*c*.

A *party wall* is a wall used or adapted for joint service between two buildings.[1]

A *foundation wall* is a wall built below the ground level, the curb level, or below the floor line nearest the ground level. See Fig. 23*b*.

A *dead wall* or *blank wall* is a wall without openings.

A *division wall* is any wall in the interior of a building.[1]

A *partition wall* is the same as a division wall.

A *partition* is the same as a partition wall.

A *bearing partition* or *bearing partition wall* is one which carries a load in addition to its own weight.

A *nonbearing partition* is one which carries only its own weight.

A *fire wall* is one which subdivides a building to restrict the spread of fire, by starting at the foundation and extending continuously through all stories to and above the roof.[2] Fire walls are used in ordinary construction and in slow-burning or mill construction where the floors cannot be depended upon to resist the full duration of a fire and are liable to collapse, or where beams and girders depend upon such walls for support.[2] Buildings of skeleton construction do not use self-supporting fire walls extending from the foundation upward as defined above but employ walls supported by the structural frame or floor system in each story. Such walls are termed "fire division walls" by the Building Code Committee of the Department of Commerce.

A *fire division wall* is a wall which subdivides a fire-resistive building to restrict the spread of fire, but is not necessarily continuous through all stories nor extended through the roof.[2]

A *retaining wall* is one the chief function of which is to resist the lateral pressure of earth or a similar material. See Fig. 23*d*.

**Parts of Exterior Masonry Walls.** — The following definitions include various elements which may be considered as parts of an exterior wall.

The *foundation* is the structure at the bottom of a wall designed to transmit the load carried by the wall to the earth. This may be some form of footing or a more elaborate foundation as described in Chapter III.

[1] Building Code recommended by National Board of Fire Underwriters.

[2] Recommended Minimum Requirements for Masonry Wall Construction, Building Code Committee, Department of Commerce.

The *foundation wall* is the part of the wall below the surface of the ground and resting on the foundation.

The *water table* is a slight projection on the outside of a wall near the ground. In some cases the water table serves to deflect the water passing over the wall surface so that it will not follow down the foundation wall. See Fig. 23*e*.

A *course* is a continuous horizontal layer of brick, stone or similar material consisting of blocks and forming part of a wall.

A *tier* is a vertical layer of brickwork with a thickness equal to the width of a brick.

The *base course* or *plinth* is usually a course of stone placed just above the ground level. A variety of stone is chosen which will resist the severe weathering action which occurs at this point.

A *belt course* or *string course* is a horizontal band which runs across the face of a wall, flush with the wall surface or projecting and either plain or molded. See Fig. 23*f*.

A *sill course* is a belt course which serves also as sills for window openings. See Fig. 23*g*.

A *sill* is the member at the bottom of a window or door opening. See Fig. 24*a*.

The *jambs* are the sides of a window or door opening. See Fig. 24*a*.

The *head* or *cap* is a member at the top of a window or door opening. See Fig. 24*a*.

*Quoins* are blocks of stone forming external corners of walls. See Fig. 24*c*. Brick used in a similar position may also be called quoins.

The *cornice* is the projection at the top of a wall. See Fig. 24*d*.

The *parapet* or *parapet wall* is the portion of a wall which extends above the roof line. See Fig. 23*c*.

The *coping* is the top cap or top course of a wall designed to shed water, to protect the top of the wall, and to give a finished appearance to the top of the wall. See Fig. 24*c* and *e*.

A *corbel* is a horizontal projection on the face of a wall formed by one or more courses each projecting over the course below.

A *gable* is the triangular-shaped piece of wall closing the end under a gable roof. See Figs. 24*d* and 131*d*.

A *saddle stone* or *apex stone* is the stone at the junction of the two inclined copings of a gable. See Fig. 24*d*.

A *kneeler* is a coping stone built securely into a gable wall to resist the sliding tendency of inclined coping. See Fig. 24*d*.

A *skew corbel* is a stone at the lower end of an inclined coping and is designed to resist the sliding tendency of the coping. See Fig. 24*d*. This is also called a kneeler.

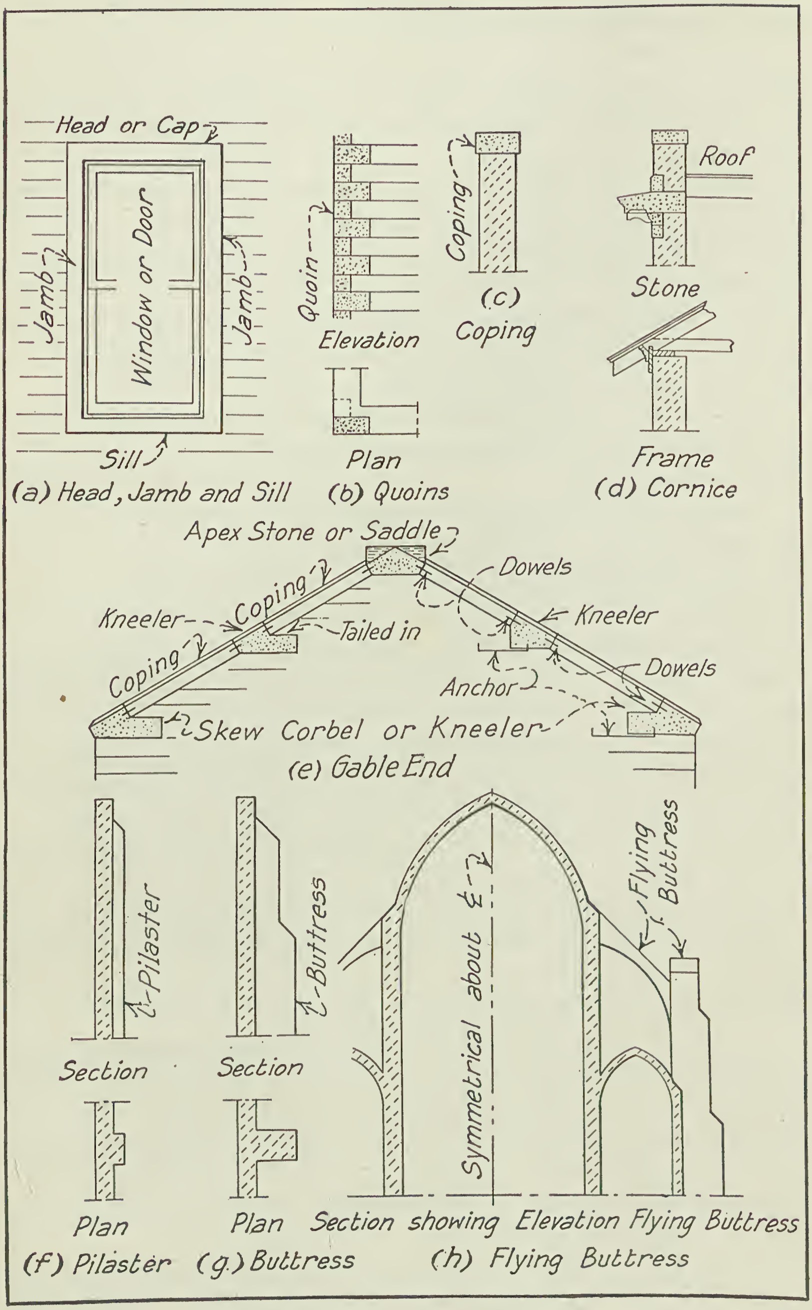



Fig. 24. Parts of a Wall

A *reveal* is the part of a jamb which is exposed between the frame and the face of the wall. See Fig. 35*d*.

A *wainscot* is a wooden lining placed on walls and partitions, usually in panels. A wainscot is commonly placed on the lower three or four feet. Other materials such as marble and terrazzo are commonly used instead of wood. A wainscot is often called a *dado*.

A *pier* is a relatively short vertical prism of masonry. It may be built up independent of other masonry in which case it is referred to as an *isolated pier;* it may be a vertical projection on the face or back of a wall to support one end of a truss or girder or to increase the lateral rigidity of the wall, in which case it is called a *wall pier*, an *engaged pier*, a *pilaster*, or a *buttress;* or it may be a short section of a wall between two openings and supporting the masonry extending over the openings.

A *pilaster* is a small vertical projection on the face of a wall to increase the rigidity or to take the reaction of a girder or truss. See Fig. 24*f*. It is sometimes called a *pier*, a *wall pier*, or an *engaged pier*. See definition of Pier.

A *buttress* is similar to a pilaster but has a greater projection. See Fig. 24*g*.

A *flying buttress* consists of a masonry pier placed at some distance from a wall and connected to it by an inclined arch. Flying buttresses are more effective than buttresses in transmitting arch thrusts to the ground. See Fig. 24*h*.

Flying buttresses were developed in the construction of Medieval Gothic cathedrals to take the thrust of the vaulted roofs constructed of stone. Modern methods of construction do not make use of the flying buttress but it is still retained as an element in architectural design. At the present time two large cathedrals are being constructed using the old Gothic principles of construction but such examples are rare. Modern methods are cheaper and fully as substantial.

The *face* of a wall is the outside surface. The *facing* is the material which forms the face.

The *back* is the inside surface of the wall. The *backing* is the material between the facing and the back.

**Parts of a Masonry Arch.** — The parts of a masonry arch are indicated in Fig. 25 and may be defined as follows:

The *arch ring* is the curved ring of masonry forming the arch.

The *span* is the width of the opening.

The *rise* is the height of the curved portion of the opening.

The *soffit* is the concave or lower surface of the arch ring.

The *back* is the convex or upper surface of the arch ring.

The *faces* are the exposed vertical planes or sides of the arch ring.

The *intrados* is the line of intersection of the soffit and a vertical plane parallel to the faces.

The *extrados* is the line of intersection of the back and a vertical plane parallel to the faces.

The *springing* lines are the lines of intersection or tangency of the soffit and the vertical, or nearly vertical, sides of the opening.

The *crown* is the highest part of the arch ring.

The *spandrel* is the space between the back of the arch ring and a horizontal plane tangent to the back of the arch ring at the crown.

The *voussoirs* are the blocks of masonry of which the arch ring is composed.

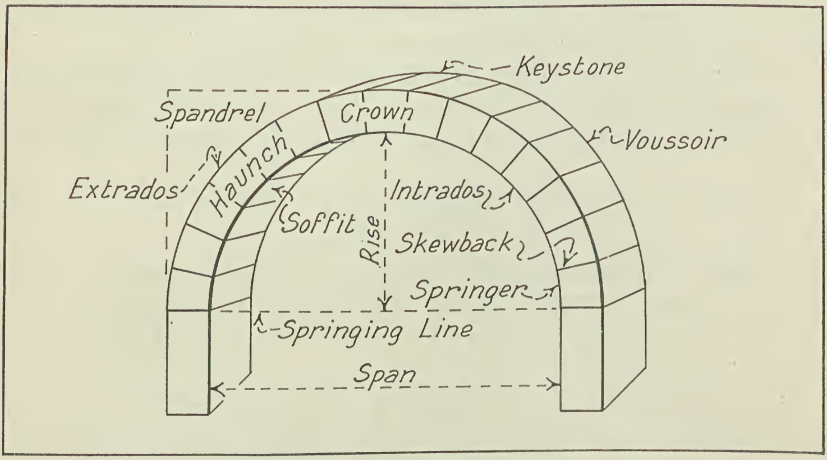



Fig. 25. Parts of an Arch

The *keystone* is the voussoir at the crown.

The *springers* are the voussoirs just above the springing lines.

The *haunches* are the sides of the arch ring.

The *skewbacks* are the upper surfaces of the springers.

The *abutments* are the masses of masonry at the sides of the opening which resist the thrust of the arch. Masonry arches which are a part of a wall do not have well-defined abutments for the wall itself serves in this capacity.

An *arcade* is a series of arches and includes the supporting members between the arches, such as piers, columns, etc.

**Curve of Arch Ring.** — Many curves and combinations of curves are used in laying out arches. When strength and economy of material are important factors as they are in arch bridges the curve of the arch ring is determined by the span and rise of the arch and the characteristics of the loading, but for the ordinary arches over openings of the walls of buildings

appearance is more of a factor in design than strength and economy of material. The most common cause of failure of arches used in building construction is due to the spreading of the abutments or the masonry which serves as abutments. This condition exists when arched window or door openings are placed too near the wall corners and the abutments at the ends of the arcade are insufficient.

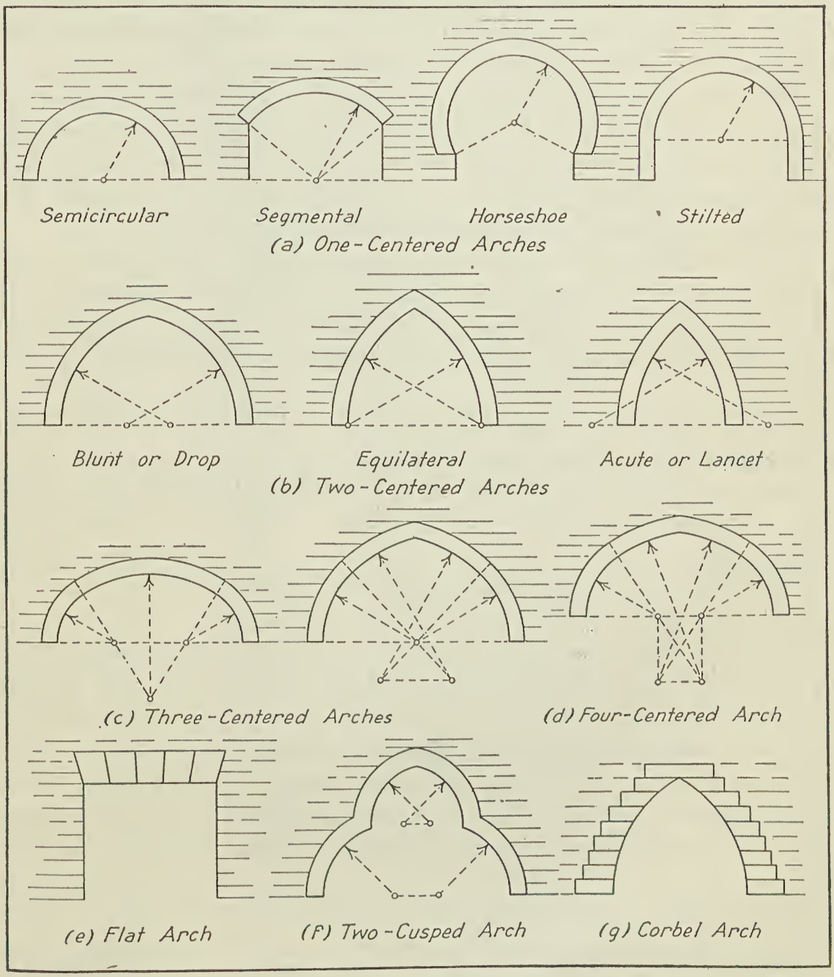



FIG. 26. Types of Arches

**Types of Arches.** — The curve of the intrados is commonly a portion of the arc of a circle or a combination of the arcs of various circles with different radii and centers. Four types which have one center, as shown in Fig. 26*a*, are the *semicircular*, the *segmental* which includes less than a

semicircle, the *horseshoe* which includes more than a semicircle and the *stilted* which consists of a semicircular arch ring with straight vertical sections added on each side.

Two-centered arches are shown in Fig. 26*b*. The three types *i.e.*, blunt, equilateral, and lancet, differ only in the relation between the radius and the spacing of the centers. In the *blunt* or *drop arch* the centers are within the arch. In the *equilateral* or *Gothic arch* the radius of the intrados equals the span and the centers are therefore on the springing lines. The centers for the *acute* or *lancet arch* are outside of the arch.

There are two types of three-centered arch as shown in Fig. 26*c*. In the first, one center is used for the arc of the central portion of the arch and two centers for the arcs at the ends of the arch ring. In the second, one center serves for the two arcs at the ends of the arch ring and two centers are required for the central portion of the arch ring.

The four-centered or *Tudor arch* as shown in Fig. 26*d* is similar to the second type of three-centered arch but the centers for the lower section of the arch ring do not coincide as in the three-centered arch. The vertical alignment of centers as shown in the figure is not essential to this type.

The *flat arch* shown in Fig. 26*e* may be supported by arch action but it is usually carried on a concealed lintel.

The *two-cusped arch* is illustrated in Fig. 26*f*. Many forms of cusped arch have been used for decorative effect. They are very inefficient structurally.

The *elliptic arch* is similar in shape to the three-centered arch shown in Fig. 26*c* but the curve of the intrados is a semi-ellipse.

The *parabolic arch* is similar in shape to the three-centered arch shown in Fig. 26*c* but the curve of the intrados is a parabola with its axis vertical.

*Groined arches* are arches which intersect each other.

The *corbel arch* shown in Fig. 26*g* is not really an arch but is called an arch because of its shape. There is no real arch action, each course being corbeled or cantilevered out over the course below until the two sides meet.

**Wall Furring.** — In general, *furring* consists of a light frame of wood or metal strips called *furring strips* applied to a surface to support plaster, stucco, or other surfacing material. It may be used to form an even surface over a rough or irregular wall or structural form; to form a hollow frame on which an imitation column, vault, or other decorative feature of plaster is placed; or to provide an air space between the rough inner surface of an outside wall and the finished surface of plaster or other finishing material, in which case it is called *wall furring*.

Wall furring has three functions:

(*a*) The air space intercepts any moisture which might pass through an outside wall and which would damage the wall finish and decorations and cause unwholesome living conditions.

(*b*) If humid air in a building comes in contact with a cold wall there will be condensation on the wall which will be just as objectionable as having water pass through the wall. The air space acts as an insulator and prevents condensation.

(*c*) The insulating properties of the air space reduce the heat transmission through a wall and thereby save fuel in cold weather and keep a building cooler in hot weather.

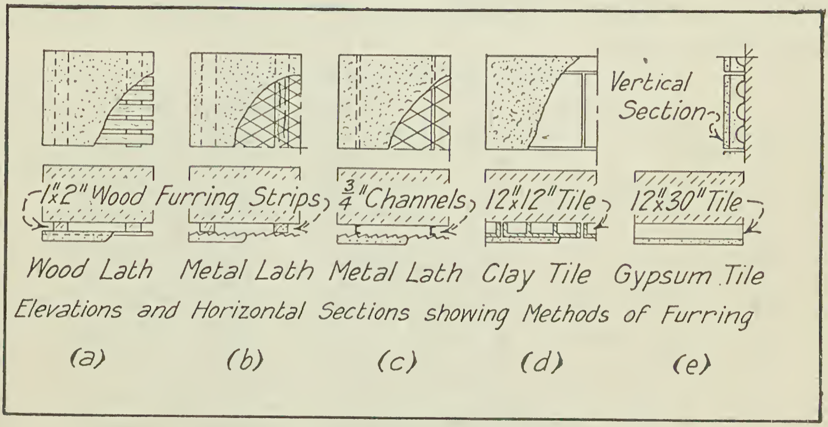



Fig. 27. Methods of Furring

There are two general methods for furring: One consists of lath and plaster placed on vertical furring strips fastened to the wall and the other of applying specially designed blocks of hollow clay tile or gypsum to the wall. The blocks are coated with plaster after being placed. The use of wood lath on wood furring strips is illustrated in Fig. 27*a*, metal lath on wood furring strips, in Fig. 27*b*, and metal lath on metal furring strips in Fig. 27*c*. Hollow clay furring tile as shown in Fig. 27*d* are fastened to masonry walls by driving nails in the mortar joints and hooking the heads over the tile. The gypsum blocks shown in Fig. 27*e* are applied in the same way.

The following comments on furring are quoted from the "Recommended Minimum Requirements for Small Dwelling Construction" by the Building Code Committee of the Department of Commerce and are applicable to all classes of buildings.

1. In regions subject to low temperature, high winds, heavy rains, or extreme humidity of considerable duration, furring of solid masonry exterior walls is

practically a necessity to avoid unwholesome living conditions caused by damp walls, and the danger of ruining wall decorations.

2. In arid localities, where low temperatures are infrequent, furring may be omitted without serious results, but should be used wherever economy in construction cost is a secondary consideration.

3. Waterproof paints or compounds applied to the interior of solid masonry walls help considerably to prevent moisture penetration, but have little effect on preventing condensation, and make it difficult to bond plaster to such treated walls.

4. Furring is somewhat less necessary on masonry exterior walls of hollow units, since the inclosed air cells help to check transmission of heat and moisture. However, mortar joints running through the wall are found to conduct moisture readily when poorly or incompletely made, and walls having such continuous joints require furring.

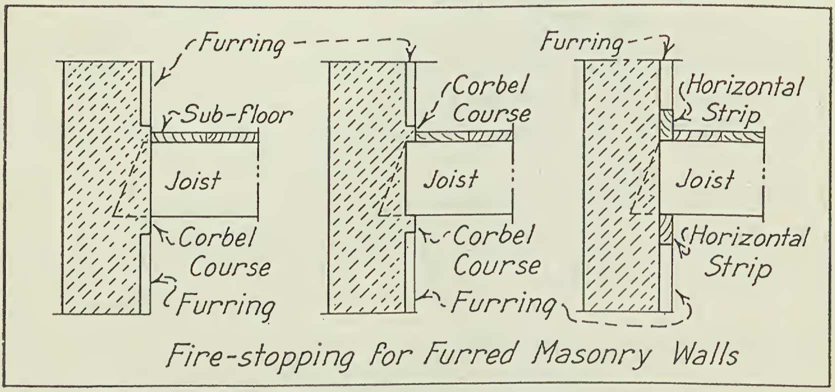



FIG. 28. Fire-stopping for Furred Masonry Walls

5. Furring a masonry wall lessens its heat conductivity, thus saving fuel, which saving, of course, continues throughout the life of the structure and may repay many times over the increased cost of furring.

6. Since hollow walls are good heat insulators, it has been found in many places that furring may be omitted and plaster applied directly to the interiors of the walls which are built with a continuous hollow space, or in which the mortar joints extend but part way through the wall.

7. In concrete house construction provision for insulation of exterior walls is recommended. A dead-air space within the wall itself or formed by furring and plastering has been found effective and this requirement seems to be favored by those recommending the use of concrete external walls.

In applying plaster to furring lath, it is important that the keys shall not project through so as to touch the wall, or be allowed to drop off and form a solid mass between the plaster and the wall. In either case moisture from the wall is liable to be transmitted through the plaster producing troublesome results, such as staining the wall, and ruining the lath — wood lath by dry rot and metal lath

by corrosion. It is claimed that excellent results in furring 8-in. brick walls are obtained by attaching a layer of tarred paper to the back of the furring strips, or by using a lath of which such paper forms an integral part. Hollow tile or gypsum furring blocks are much used and are quite satisfactory. They have grooves in the back face which furnish air spaces between the wall and the plaster. There are also several forms of metal furring to which metal lath is attached and which serve the same purpose. Where walls are likely to be continuously damp, hollow tile furring will be more satisfactory than gypsum.

To prevent the passage of fire from floor to floor behind the furring it may be necessary to corbel the masonry walls as shown in Fig. 28. This is not necessary if fireproof floors, coming in close contact with the walls, are used.

### Thickness of Masonry Walls

**Factors Affecting Wall Thickness.** — The principal factors which are commonly considered as affecting the thickness of masonry walls used in building construction are:

1. Loads to be carried.
2. Resistance to fire.
3. Kind and quality of the material used.
4. Charactor of occupancy.
5. Function of wall.
6. Height of wall above section considered.
7. Story height.
8. Spacing of buttresses and cross walls.
9. Window and door openings, chases, recesses, etc.
10. Span of beams bearing on wall.
11. Bond between face and backing.

Each of these items will be discussed in detail.

Building codes specify the minimum thickness which will be permitted under any circumstances. They also specify requirements which must be met in order that the minimum wall thickness may be used and they give allowable working stresses which may make it necessary to use thicknesses greater than the minimum in order to carry the loads to which the walls are subjected. The building codes of the various cities give the requirements which must be met for the plans of a building to receive the approval of the building departments and for the completed building to be acceptable to those departments. The engineer or architect may adopt requirements which are more severe than those of the building code but he must not be less severe.

The discussion concerning masonry walls will be based quite largely on the following: The Report of the Building Code Committee of the De-

partment of Commerce entitled "Recommended Minimum Requirements for Masonry Wall Construction"; The Building Code recommended by the National Board of Fire Underwriters; and the building codes of various cities.

**Loads.** — Masonry walls must be of sufficient thickness to carry the loads due to their own weight, the loads which are transmitted to them by the floors and the roof, and the loads due to wind and earth pressure without exceeding the specified working stresses. Building codes specify the live loads to be used for various classes of occupancy as described in Article 3.

**Resistance to Fire.** — There are three factors which must be considered in connection with the fire resistance of walls. The material of which the wall is constructed must be fire resistive; the walls must be thick enough to prevent the transmission of heat to such an extent that the structure or contents of adjoining buildings may be damaged; and the walls must be thick enough to satisfactorily resist the tendency to bulge and collapse in case of severe fires.

The following quotation is taken from a report of the Building Code Committee of the Department of Commerce:

> The committee has decided that walls thick enough to meet the general requirements of stability and compressive strength will be of sufficient thickness to withstand ordinary fire exposures and that, except in the case of fire walls between buildings or parts of buildings where very hot or long continued fires may be expected, no account need be taken of resistance to heat transmission in deciding on the necessary thickness of walls.

**Kind and Quality of Material.** — Masonry walls are constructed of the following materials: Brick, stone, hollow clay tile, concrete block, concrete, and various combinations of these materials.

In considering the requirements for walls of various materials two factors must be taken into account: the strength and the stability of walls constructed of each material. For example, where strength is a controlling factor, ashlar stone walls may be made thinner than brick walls but where the stresses in the materials are low and stability is the important factor the two materials are considered as equivalent.

The quality of the materials is controlled by specifications and tests. The engineer or architect may write his own specification for materials but, in general, the specifications of recognized authorities should be used. The American Society for Testing Materials has prepared specifications for a large number of structural materials and these specifications should be adopted wherever possible. Other organizations have prepared specifications which may be considered as standard. The

building code for each city specifies the minimum requirement for the quality of the materials for use in that city.

The stresses to which materials may be safely subjected are called *working stresses.* Codes and specifications give the working stresses for masonry walls of various materials.

**Character of Occupancy.** — Building codes quite commonly call for the minimum thickness of walls of industrial buildings such as warehouses and factories to be greater than the minimum thickness of walls of large residence buildings such as hotels and apartment houses in cases where the loads do not require the heavier walls. Since strength is not the controlling factor, the only reason for this requirement seems to be the desire to secure greater stability for the industrial buildings. The Building Code Committee of the Department of Commerce does not agree with this practice and makes the following statements:

> Heavier floor loads, where not exceeding the allowable unit stresses, increase the vertical components of the applied pressure and add to the stability of the walls against lateral forces thereby giving the industrial buildings an advantage as compared with the residential buildings.
>
> Within the economic height of buildings with brick bearing walls the industrial or commercial building is more apt to have a rigid interior framework than the residential building.

The smaller residential buildings such as dwelling houses are so different in construction and use that they require special regulations concerning minimum wall thicknesses. The 8-in. wall is used quite extensively in dwelling house construction because the walls are short, they are supported at frequent intervals by interior partitions, and since the walls are low the consequences would not be serious if such walls should fall during a fire.

**Functions of Wall.** — Where loads are not the controlling factor, fire walls are commonly required to be thicker than bearing walls of corresponding height and nonbearing walls may usually be thinner than the corresponding bearing walls. A separation of at least 4 in. of solid masonry is required in fire walls and party walls between combustible members which enter such walls from opposite sides. Panel walls in buildings of skeleton construction may usually be made 8 in. or 12 in. thick for any of the common masonry materials. Partitions may be made much thinner than exterior walls.

**Height of Wall.** — The minimum thickness permitted for any section of a wall depends upon the distance of that section from the top of the wall. This distance is sometimes measured in feet but more often in stories with a maximum limit set on the story height.

The Building Code Committee of the Department of Commerce measures the height in feet and recommends that:

The minimum thickness for solid brick exterior bearing or party walls shall be 12 in. for the uppermost 35 ft. of their height and shall be increased 4 in. for each successive 35 ft. or fraction thereof.

The committee further recommends that:

Solid brick walls be supported at right angles to the wall face at intervals not exceeding eighteen times the wall thickness in the top story and twenty times the wall thickness elsewhere. Such lateral support may be obtained by cross walls, piers, or buttresses, when the limiting distance is measured horizontally, or by floors when the limiting distance is measured vertically.

The Building Code of the National Board of Fire Underwriters measures the height in stories as follows:

For all brick bearing walls of buildings of the dwelling house (residence) class, the upper three stories shall be not less than 12 in. thick, increasing 4 in. in thickness for each three stories or fraction thereof below. No three-story increment shall exceed 45 ft. in height.

**Story Height.** — The unsupported height between stories is an important factor in the stability of walls and for that reason is restricted by all building codes. The story height permitted by various codes varies from 15 times the wall thickness to 20 times the wall thickness. This ratio may be larger for solid masonry walls than for walls constructed of hollow brick, because weight is an important factor in stability and this ratio is usually larger for the lower stories than it is for the top story where the vertical loads which contribute to the stability are small. When walls are dependent upon floors for their lateral support, provision must be made in the buildings to transfer the lateral forces resisted by all floors to the ground.

Special provisions are made to cover excessive story heights such as exist in theaters and auditoriums. The lateral support provided in a horizontal direction by the floors may also be provided by vertical buttresses or cross walls. When buttresses and floors are used together to provide lateral support the minimum wall thickness required for a given story height may be reduced, according to some codes.

Buttresses may entirely replace the floors so far as lateral support is concerned. These factors are considered in the paragraph on the spacing of buttresses.

The unsupported length of isolated piers is usually limited to 10 times the least dimension.

**Spacing Buttresses and Cross Walls.** — As explained under the paragraph on "Story Heights," the minimum thickness for walls is dependent upon the degree of lateral support. Lateral support may be provided by the floors or by vertical elements such as buttresses and cross walls. The Building Code Committee of the Department of Commerce recommends that the minimum wall thickness shall be a specified fraction of the story height or of the spacing of cross walls or properly designed buttresses, the smaller of the two values being used.

If floors and buttresses are used together to provide lateral support, some codes permit the maximum wall thickness, as determined by the height of wall or the story height, to be reduced by one-half the projection of buttresses. The requirements for the width of buttress vary from $\frac{1}{8}$ to $\frac{1}{12}$ the clear distance between buttresses and the requirements for the clear distance between buttresses vary from 18 to 24 times the wall thickness. The minimum thicknesses for the wall between buttresses is commonly 12 in.

Some codes require that the same amount of material be used for walls with buttresses as required for plain walls. Where buttresses are used they are required to be so placed that the principal girders and trusses will bear on them.

If the length between cross walls or buttresses is greater than from 50 to 100 ft., depending upon its thickness and upon the code under consideration, an increase of 4 in. in the minimum wall thickness is frequently required. This requirement is to reduce the tendency of long walls to buckle and fall due to the expansion produced by heat in case of fire.

**Window and Door Openings, Chases, Recesses, etc.** — The Building Code Committee of the Department of Commerce makes the following statement concerning the effect of openings on the prescribed minimum wall thickness:

> It is customary in about one-third of existing codes to require that bearing walls be increased 4 in. in thickness when a certain percentage of the wall section (varying in different codes from 25 to 55 per cent) in any horizontal plane is removed for openings. This practice is a survival from the period when maximum masonry stresses were not prescribed and the increase of thickness was required to take care of possible excessive stresses in walls thus reduced in section. If the compressive stresses in masonry walls are kept within the prescribed limits and if serious eccentricity in loading of piers and short wall sections is avoided, it is believed unnecessary to require increase in wall thickness on account of openings.

It is common practice to leave vertical and horizontal grooves on the inside of masonry walls to accommodate steam and water pipes, electrical

conduit, etc. These grooves are often of considerable size. Such grooves are called *chases*. They are covered over by the plaster surface so that the pipes are concealed. It is also common practice to provide depressions in the inside of masonry walls to permit radiators, switch boxes, etc., to be set back in the walls so that their faces will be flush with the wall face. Such depressions are called *recesses*.

The following recommendations of the Building Code Committee of the Department of Commerce represent good practice and apply to all kinds of masonry walls:

There shall be no chases in 8-in. walls or within the required area of any pier, or no chase in any wall or pier shall be deeper than one-third the wall thickness. No horizontal chase shall exceed 4 ft. in length, nor shall the horizontal projection of any diagonal chase exceed 4 ft.

Recesses for stairways or elevators may be left in walls, but in no case shall the walls at such points be less than the required thickness of walls at the fourth story above the ground floor unless reinforced by additional piers, by steel or reinforced-concrete girders, or steel or reinforced-concrete columns and girders securely anchored to the walls on each side of such recesses. Recesses for alcoves and similar purposes shall have not less than 8 in. of material at the back. Such recesses shall be not more than 8 ft. in width and shall be arched over or spanned with lintels.

The aggregate area of recesses and chases in any wall shall not exceed one-fourth the whole area of the face of the wall in any story.

No chases or recesses shall be permitted in fire or fire division walls that will reduce the thickness below the minimum specified in this code.

Openings for doors and windows shall have well-buttressed arches or lintels of masonry, or of metal with bearings at each end of not less than 4 in. on the wall. On the inside of openings less than 4 ft. wide, in which the thickness of arches and lintels is less than that of the wall supported, timber may be used, which will rest at each end not more than 2 in. on the wall and be chamfered or cut to serve as arch centers.

Vertical chases should be filled with solid masonry at each floor. Many codes require that horizontal chases be filled with concrete or brickwork after the pipes are placed. The codes which have this requirement usually permit horizontal chases to be 7 ft. long instead of the more common limit of 4 ft.

**Span of Beams.** — Building codes commonly require that when the clear span of a floor is greater than 26 ft., the thickness of bearing walls supporting the floor shall be increased 4 in. over that normally required, for each 13 ft. or fraction thereof that the span exceeds 26 ft.

The Building Code Committee does not agree with this requirement. It states that:

This practice is believed to date back to the era when working stresses for masonry were not limited directly, but by controlling the live loads likely to come upon the walls. Where masonry stresses are kept within the prescribed limits, the spans of floor beams should not affect the required thickness of masonry walls.

**Bond.** — Walls which are not constructed of the same material throughout their thickness but which have a facing of stone or special brick must meet certain requirements concerning the bond or tie between the face and the backing in order that the face material may be included as a part of the required wall thickness. These requirements depend upon the materials used and are discussed in the articles which follow.

**Materials.** — Many different materials are used for constructing walls and partitions, the most common being brick, stone, hollow clay tile, and concrete which are classed as fireproof materials, and wood siding, stucco or plaster supported by wood studs which are classed as non-fireproof materials.

Each of these will be considered in subsequent articles.

## ARTICLE 18. BRICK MASONRY

Brick for structural purposes may be made of clay; portland cement and sand; lime and sand.

Clay brick exterior walls are used in all classes of building construction from small dwelling houses to the finest public buildings. Concrete or cement brick and sand-lime brick are used to a limited extent.

### Manufacture, Properties, and Classes of Brick

**Manufacture.** — Clay brick are made by three different processes: The Soft-Mud Process, the Stiff-Mud Process, and the Dry Process. In all of these processes the brick are molded to the desired shape, dried, and burned in kilns. The chief difference in the processes is in the method of molding.

In the *soft-mud process* the clay is mixed with water and worked into a uniform plastic mass. Brick are shaped by pressing this material into molds by hand or machinery. To keep the brick from sticking to the molds the molds may be wet with water or they may be sanded. If the molds are wet the method is known as *slop-molding* and the brick are called *water-struck brick*. If the molds are sanded the method is known as *sand-molding* and the brick are called *sand-struck brick*.

In the *stiff-mud process* just enough water is used with the clay to produce a mixture which may be forced through a die forming a ribbon of

which the cross-section equals that of the flat side or bed of a brick, or the end. The brick are cut from this ribbon by tightly stretched wires, forming *wire-cut brick.* If the beds are cut by the wires the brick are called *side-cut* but if the ends are cut they are called *end-cut.*

In the *dry-pressed process* the clay of dry consistency is pressed into gang molds with plungers exerting a heavy pressure. This process produces the most accurately formed brick.

Brick which are pressed in oversize molds, dried, and then repressed to the correct size are called *repressed brick.* Such brick are accurately formed and strong. Stiff-mud brick are frequently repressed.

Clay brick are very extensively used in all parts of the country. By selection of clays and introducing certain oxides, face brick of various colors are produced.

Concrete or cement brick are usually made by pressing a rather dry mixture of portland cement, sand, and water into gang molds. On account of the dry mixture used the molds can be immediately moved without waiting for the cement to set. The brick are placed in an atmosphere of steam or are sprayed with water while the cement is setting. This class of brick should be called *concrete brick* rather than cement brick.

The ordinary concrete brick is a dead cement color which is not suitable for face brick. Different finishes are made on the exposed face by putting aggregates or colored cements on one side of the mold before pressing and backing this up with an ordinary mixture.

Concrete brick are quite widely used in some parts of the country, particularly where suitable clay for brick making is scarce.

Sand-lime brick are made of a mixture of sand and hydrated lime pressed into shape in molds and cured in an atmosphere of steam which causes chemical action to take place between the sand and lime thereby cementing the materials together.

**Size, Shape and Unit of Measure.** — The standard size for American face brick is $2\frac{1}{4} \times 3\frac{3}{4} \times 8$ in. but brick made in the same size molds will differ in size on account of the variation in the amount of shrinkage of different clays in burning. Roman brick which are used to a limited extent are $1\frac{1}{2} \times 4 \times 12$ in., Norman brick $2\frac{3}{4} \times 4 \times 12$ in., and English brick $3 \times 4\frac{1}{2} \times 9$ in. The various sizes of brick are shown in Fig. 29*a*.

Special shapes are available for use in forming a finish around openings or for moldings. These special shapes are not commonly used for ordinary brickwork but are available in face brick and in the glazed and enameled clay brick described later. The most common forms are the *bull-nose* and *double bull-nose* shown in Fig. 29*b* for use where a rounded

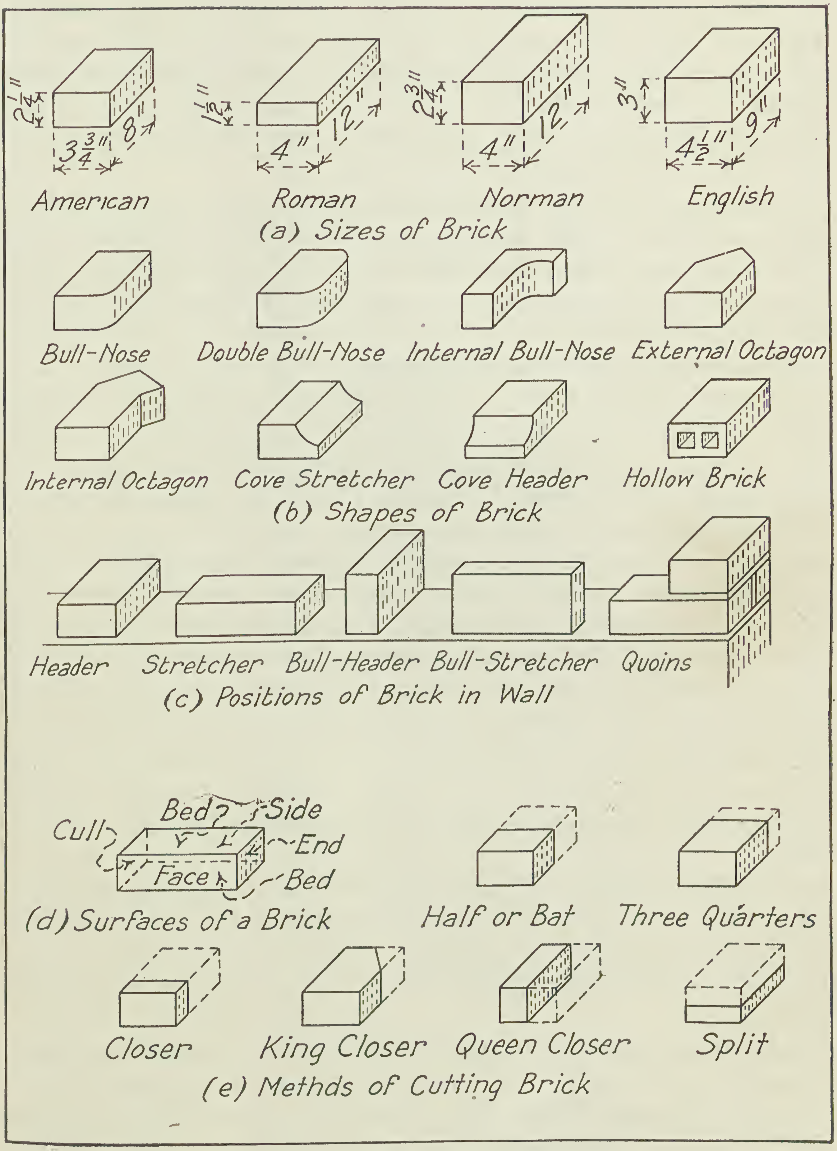



Fig. 29. Brick Types and Dimensions

corner is desired. Other shapes are the *internal bull-nose*, the *external octagon*, the *internal octagon*, and the *cove header* and *stretcher* as shown in Fig. 29*b*. *Hollow brick* as shown in Fig. 29*b*, are made for use as face brick or backing brick to reduce the weight of a wall and to get the advantage of the air space in heat insulation and checking the passage of moisture through the wall.

The six surfaces of a brick are sometimes called the *face*, the *side*, the *end*, the *cull*, and the *beds* as shown in Fig. 29*d*.

Brick may be cut into pieces of various shapes the more common of which are shown in Fig. 29*e* and are known by the following names: *Half* or *bat*, *three-quarter*, *closer*, *king closer*, *queen closer*, and *split*. They are used to fill in the spaces at the corners and in other places which the full brick will not fit.

Brick are always sold by the thousand.

**Hardness of Clay Brick.** — The durability of a clay brick depends largely upon the degree of burning it has received in the kilns. In removing brick from a kiln they are sorted according to their hardness which depends upon the degree of burning. The brick which immediately surround the fire are usually overburned and are badly warped and discolored. These are known as *arch* or *clinker brick* and are suitable for use in foundations or similar places for they are very durable but unattractive. The brick which have received the right amount of burning are known as *hard* or *well-burned brick* and are suitable for general use. The brick which are the most remote from the fire are underburned and are known as *soft brick*. These brick are weak and will not resist the action of the weather. They are only suitable for use as backing brick where moisture is not encountered and where strength is not an important factor. The terms *salmon*, *pale* and *light* are often applied to soft red brick.

**Color of Clay Brick.** — Common brick used where appearance is not a factor are usually made of clay which burns red, but in some cases common brick are white or cream-colored. Very attractive walls have been built of common brick by careful selection of the brick, the type of joint and the bond.

Brick used on exposed faces of walls where the appearance is a factor are known as face brick. By the mixing of clays and introduction of certain oxides a great variety of colors may be secured. The most common colors are various shades of red, brown, and gray. Many effects are produced by the fire markings in burning.

**Surface Finish of Clay Brick.** — The exposed face of brick may be smooth or may be roughened by *wire cutting* or by *combing*, as in *tapestry brick*.

*Glazed brick* are smooth-faced brick of special composition which will permit a glaze being formed on the face exposed to the gases in the furnace produced by throwing salt into the fires of the kiln. This is called a *salt glaze* and does not require an additional burning. The common colors of salt glaze are gray, brown, and green. Salt-glazed brick are impervious, smooth, and easily cleaned. They are suitable for interior as well as exterior use, the whole wall surface being covered or simply the wainscoting.

*Enameled brick* are made by coating the surface of smooth unburned clay brick of special composition with a wash which gives an enameled surface when the brick are burned. The common colors are white, green, and brown and the surface may have a bright, medium, or dull finish. Enameled brick are impervious, smooth and easily cleaned. They possess these qualities to a higher degree than salt-glazed brick and are more expensive. Enameled brick are suitable for interior and exterior use. They are particularly desirable for swimming pools, hotel kitchens, and in other positions where wall tile might also be used.

*Fire-flash* or *fire-mark* brick are those brick which have acquired an attractive surface marking by exposure to the fires of a kiln.

**Face, Backing, and Common Brick.** — Brick are divided into *face brick* and *backing brick* according to the part of the wall in which they are placed. Face brick are those which are used in the exposed face of a wall whereas backing brick are those which are used in the back of the wall. Face brick are of higher quality, greater durability, and better appearance, than backing brick. Backing brick may often come from the same kiln as the face brick but they are of inferior quality due to underburning or overburning.

Brick are also divided into *face brick* and *common brick.* In this classification brick which are made especially for facing purposes by selecting the clays to produce the desired color or by special surface treatment are called face brick, whereas brick which are made from the natural clay and do not have a special surface treatment are called common brick. Selected common brick are frequently used for face brick. They frequently have attractive fire marks.

**Quality of Brick.** — The quality of brick is determined by its strength, durability, and appearance.

"Standard Specifications for Building Brick" have been adopted by the American Society for Testing Materials. These specifications refer to strength and durability and measure those qualities by determining the amount of water that samples of brick will absorb under specified conditions, their compressive strength, and their strength when tested as a beam with a load at the center. According to the results of these physi-

cal tests, clay brick are classified into: *vitrified brick, hard brick, medium brick,* and *soft brick.* This classification is also applied to sand-lime brick although the process of manufacture does not produce brick which are vitrified but they may pass the same tests.

"Standard Specifications for Concrete Brick" have been adopted by the American Concrete Institute and "Tentative Specifications" by the American Society for Testing Materials.

## Brick Masonry

Brick masonry consists of brick built up to form walls or other structural elements. In order to secure an even bed for the brick, to hold them in position, to make a tight wall, and to improve the appearance, mortar is used between the brick and forms the *joints.* The brick are held together so that they will act as a unit by arranging them so that they lap over each other and break the vertical joints. The various arrangements which are used are called *bonds* and affect the appearance of the masonry. Brick may be arranged to carry out designs or *patterns* which have no bonding effect.

**Headers, Stretchers, etc.** — Brick may be placed in various positions in a wall. If they are laid flat with the end exposed they are called *headers,* and if laid flat with long side exposed they are called *stretchers.* Half-brick which are used to give the appearance of headers but which do not project into the backing are called *false headers.* For sills, belt courses, etc., brick may be placed on edge with the end exposed in which case they are called *bull headers.* Occasionally they are laid on edge with the flat side exposed forming *bull stretchers.* Belt courses and flat arches may be formed of brick set on end with the narrow side exposed. Such brick are called *soldiers. Quoins* are brick placed at corners with one end and one side exposed. These classes of brick are illustrated in Fig. 29*c*.

**Bonds.** — The arrangement of brick in a wall to tie the parts together by lapping the brick in various ways is called the *bond.*

In *running* or *stretcher bond* the face brick are all stretchers as shown in Fig. 30*a* the face brick being tied to the backing by metal ties placed in the horizontal joints, by using clipped or secret bond as described later, or by splitting the face brick of every sixth course in half lengthwise so that a continuous row of headers may project halfway through the course and into the backing.

In *common* or *American bond* every sixth course of stretcher bond is made a header course, as shown in Fig. 30*b*. This gives a much stronger wall than that secured with metal ties.

*English bond* consists of alternate courses of headers and stretchers, the vertical joints in the header courses all coming over each other and the

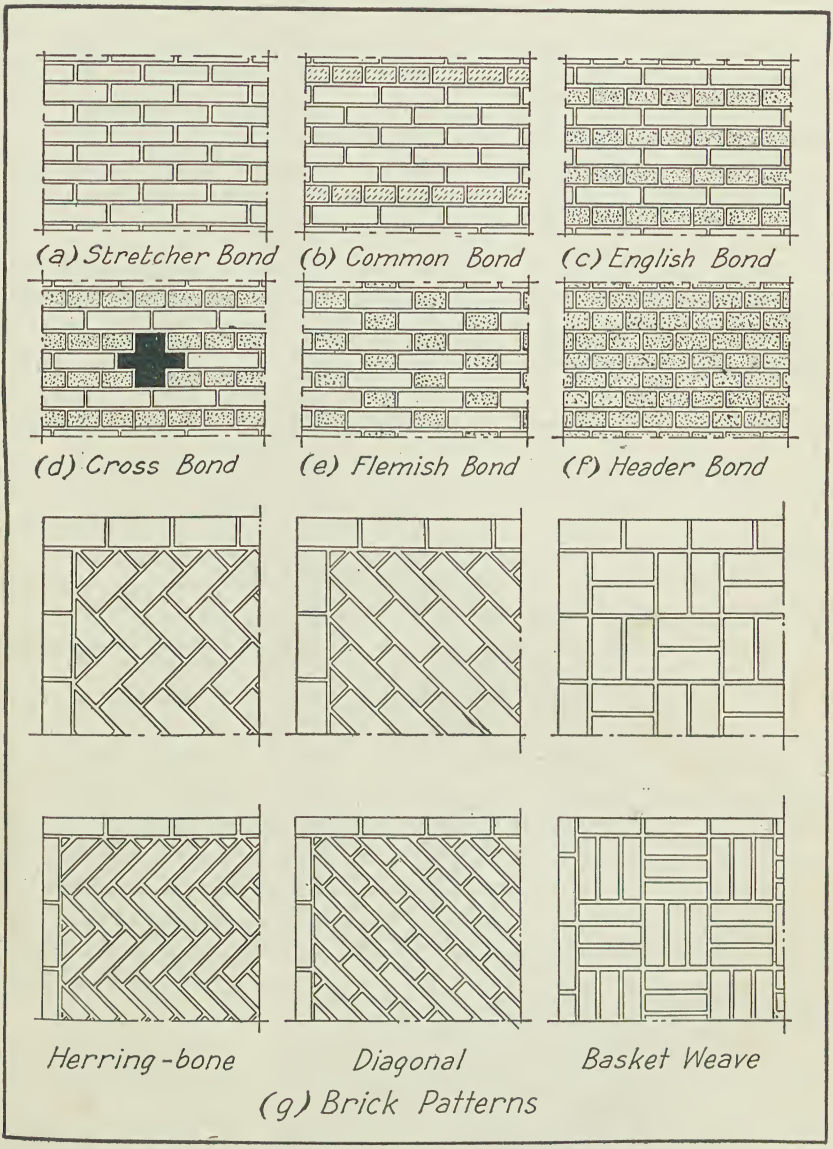



Fig. 30. Brick Bonds and Patterns

vertical joints in the stretcher courses also being in line. The vertical joints in the stretcher courses bisect alternate brick in the header courses, as shown in Fig. 30*c*.

*English cross bond, Dutch bond,* or *cross bond* is similar to English bond but the alternate courses of stretchers break joints as shown in Fig. 30*d*. This wall is seen to be built up of interlocking crosses consisting of two headers and a stretcher one of which is shown black in the figure.

In *Flemish bond* each course consists of alternate headers and stretchers, the alternate headers of each course being centered over the stretchers in the course below, as shown in Fig. 30*e*.

*Header bond* consists entirely of headers laid to break joints. An entire wall would not usually be laid in header bond but certain areas of a wall may be laid in header bond for decorative effect. See Fig. 30*f*. A large part of the headers may be false headers.

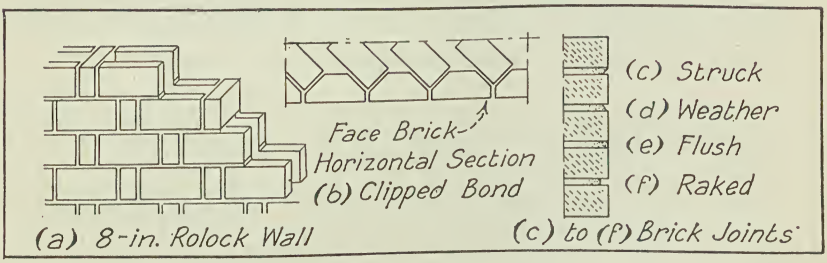



FIG. 31. Rolock Wall, Clipped Bond, and Types of Joints

In *clipped* or *secret bond* face brick are laid in running bond but the inside corners of the brick in every sixth row are clipped to permit a tie to be made with backing by headers laid diagonally as shown in Fig. 31*b*. This bond offers very little resistance to the separation of the face and backing, so it is frequently desirable to use metal wall ties in addition to the clipped bond. These ties should be used on every brick of the course halfway between the diagonal header course. This construction gives a stronger wall than the use of wall ties only but is not as satisfactory as the other bonds which have been described.

The metal *wall ties* may be galvanized iron strips not thinner than No. 26 U. S. Standard Gage 1 in. wide and about 6 in. long corrugated to give better bond, or ties may be made of heavy galvanized wire not smaller than No. 12 B. & S. Gage bent into the shape of the letter S.

Hollow brick walls are sometimes constructed of bull headers and bull stretchers in Flemish bond as shown in Fig. 31*a*. The advantages claimed for this type of wall are the saving of material and labor, the heat insulating properties of the air space, and the checking of the passage

of moisture by the air space. This type is often called the *row-lock* or *rolock wall.*

**Patterns**. — A great variety of patterns may be worked out by the use of headers and stretchers arranged in various ways. These may be emphasized by using headers differing slightly in color from the stretchers. Other patterns are secured by arranging face brick in diagonal and vertical positions. The most common patterns of these are the *herring-bone,* the *diagonal,* and the *basket-weave* patterns shown in Fig. 30*g*.

**Skintled Brickwork.** — Skintled brickwork consists of setting the face brick as in running bond but so that they are out of line with the face of the wall. The corners may project or be recessed from $\frac{1}{8}$ in. to $\frac{1}{4}$ in. or more. The mortar which squeezes out of the joint may be allowed to remain. Very attractive effects may be secured with skintled brickwork.

**Joints.** — The mortar layers between brick are called *joints.* The joints used in brick masonry may be as thin as $\frac{1}{8}$ in. for enameled or glazed brick walls where a surface which is easily cleaned is desired, or they may be as thick as $\frac{3}{4}$ in. to secure certain architectural effects, the most common thickness being from $\frac{3}{8}$ in. to $\frac{1}{2}$ in.

The joints in brickwork are usually made by the following operations all of which are performed with a trowel:

1. Spreading enough mortar to form the horizontal joint for three or four brick.

2. Cutting off the mortar which projects over the edge to keep it from running down over the face of the wall.

3. Bedding the brick one at a time by tapping with the trowel until they are in position.

4. Cutting off the mortar which has been forced over the edge by the bedding process and buttering the end of the brick to form the next vertical joint. This forms a rough cut joint.

5. Jointing or finishing the exposed surface of the joints. The various types of joints are shown in Fig. 31*c* to *f*. This method does not fill the vertical joints.

*Push* or *shove* joints are formed by placing a brick on a heavy bed of mortar and pushing or shoving it into position against a brick in the same course which has already been placed, in such a way as entirely to fill the vertical joint between the two with mortar. Walls constructed in this manner are stronger and more watertight than walls constructed in the usual way.

*Buttered joints* are formed by holding the brick bottom up and buttering mortar on the bottom around the four edges of the bed and on the vertical edge which will come in contact with the last brick laid. The

brick is then placed and tapped with the handle of the trowel to set it accurately. Narrow joints in enameled or glazed brickwork are usually formed in this way. At one time face brick were set with buttered joints $\frac{1}{8}$ in. wide but this practice has been practically discontinued. With buttered joints the mortar is around the edges of the brick but not under the central part.

The exposed face of mortar joints may be finished in various ways. This finish is always formed at the time the brick are laid and not afterwards as in pointing stone work.

The *struck joint* shown in Fig. 31*c* is the most common type used when a finished joint is required.

The *weather joint* shown in Fig. 31*d* is similar to the struck joint but slopes in such a way that it is more effective in shedding water. The weather joint is more difficult to form than the struck joint so is rarely used.

In the *flush joint* shown in Fig. 31*e* the mortar is cut off flush with the face of the brick. This type of joint is common for unexposed interior surfaces and is also widely used for face brick.

The *plain* or *rough-cut joint* is similar to the flush joint but is not made as carefully. It is the cheapest and easiest to form and is used where the appearance is not a factor.

The *raked joint* shown in Fig. 31*f* is formed by raking out the mortar to the depth of about $\frac{1}{2}$ in. Very attractive effects may be secured with raked joints properly used. A joint similar to the raked joint is sometimes formed by placing wood strips in the joints as the brick are being laid. These strips insure a joint of uniform thickness. They may be removed as soon as the mortar has set slightly. This is called the *stripped joint.*

The brickwork for all party walls, fire walls, and bearing walls carrying heavy loads should be laid solid with all joints filled with mortar.

**Mortar.** — The mortar used for brickwork above ground is usually a lime mortar consisting of 1 part by volume of slaked lime (lime putty) or dry hydrated lime, and not more than 4 parts by volume of sand mixed with the proper amount of water to make it workable.

Cement mortar consists of 1 part of portland cement to not more than 3 parts of sand proportioned by volume. In order to increase the workability and possibly the watertightness, not more than 15 per cent of the cement by volume may be replaced by an equal volume of dry hydrated lime. The lime and cement should be thoroughly mixed before the addition of water. The mortar must be used immediately after the water is added. Cement mortar is used for laying brick in foundation walls where they will be subjected to moisture, for bearing walls where

the strength is of importance, and for fire walls where its resistance to fire is of value.

Cement-lime mortar is made of 1 part portland cement, 1 part slaked or dry hydrated lime, and not more than 6 parts of sand proportioned by volume. This mortar is stronger and more durable than lime mortar, but is excelled by cement mortar.

Mortar is sometimes made of 1 part natural cement to 3 parts sand proportioned by volume. This makes a better mortar than lime mortar but it is inferior to portland cement mortar.

The sand used in making mortar should be clean, but sharp sand is not necessary. Coarse sand is better than fine sand but a sand graded from fine to coarse is better than either.

Mortar of almost any color may be produced by mixing mineral mortar colors with the mortar. Mortar colors may be in the form of a paste or a powder. The common colors are red, brown, chocolate, and black but many other colors are available or can be secured by mixing colors.

**Wetting Brick Before Laying.** — All brick should be thoroughly wet just before being laid, except in freezing weather, when they should be laid dry. The bricks are wet to keep them from soaking the water out of the mortar where it is necessary for proper setting, to secure a better bond between the brick and mortar and to wash off the dust on the brick. In freezing weather, brick which have been wet may be coated with a thin film of ice which will keep the mortar from penetrating into the brick and securing a hold.

**Bond Required.** — Every sixth course on both sides of a wall should be a header course, except where walls are faced with brick in Flemish bond and English bond, in which case the headers of every fourth course should be full brick bonded into the backing. The remaining headers may be half brick called false headers. Where running bond is used, it should be bonded into the backing by using clipped bond combined with metal wall ties as described in the paragraph on clipped bond, or by using split stretchers as described in the paragraph on running bond.

In walls more than 12 in. thick the inner joints of header courses should be covered with another header course which shall break joints with the course below.

Desirable methods of bonding brick walls of various thickness and types are shown in Fig. 32.[1]

Face brick should be laid at the same time as the backing. The walls of each story should be built up the full thickness to the top of the beams or joists above.

[1] Report of Building Code Committee of the Department of Commerce.

**Anchorage at Wall Intersections.** — All walls should be securely anchored and bonded at points where they intersect. Where such walls are not built at the same time, the perpendicular joint should be regularly toothed with 4 in. offsets, and the joint should be provided with anchors

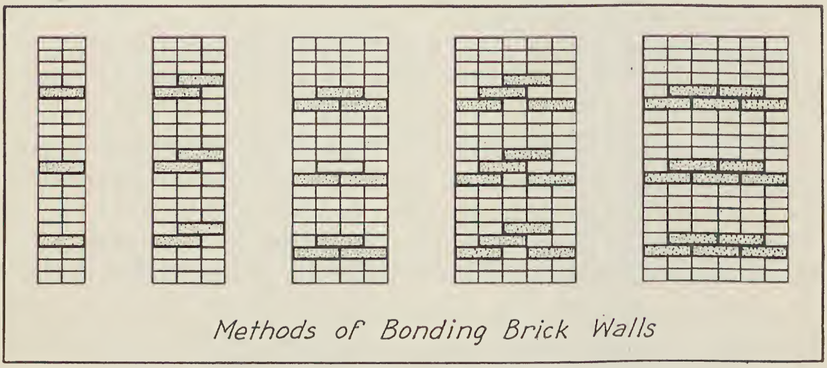



FIG. 32. Methods of Bonding Face Brick and Backing

of not less than 2 in. by $\frac{3}{8}$ in. metal, with bent up ends or cross pins to form anchorage; such anchors to be not less than 3 ft. long, extending 18 in. on each side of the joint and spaced not more than 3 ft. apart in height.[1]

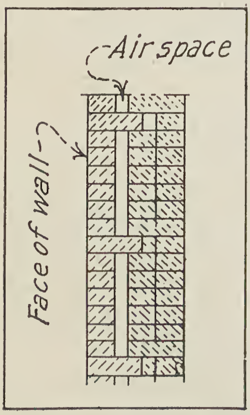



FIG. 33. Hollow Brick Wall

**Hollow Walls.** — Hollow brick walls of the rolock type are formed of bull stretchers and bull headers as shown in Fig. 31*a*. Another method of constructing hollow walls is shown in Fig. 33. Exterior walls are sometimes constructed hollow to secure the heat insulation of the air space and the advantage of this space in preventing the passage of moisture thereby avoiding furring.

In the rolock type of wall the bull headers provide cross ties but in other hollow walls the face is built independent of the backing to which it is tied by headers or by metal ties which should be placed not over 24 in. apart horizontally and vertically. These ties should have their ends bent at right angles; they should be not less than 1 in. wide by $\frac{1}{4}$ in. thick; and they should extend into the wall on each side not less than 4 in.

The same net horizontal section as required for solid walls should be used, no advantage being taken of the increased thickness due to the air

[1] *Ibid.*, page 135.

space. This requirement does not apply to rolock walls which are permitted on small dwelling houses only and the height of which should not exceed 20 ft. if 8 in. thick, or 30 ft. in any case.[1]

**Stucco or Brick.** — Exterior walls of brick are frequently covered with stucco. In this case the surface brick should be rough hard-burned arch brick set in portland cement mortar with joints not less than $\frac{3}{8}$ in. thick, and with the mortar raked out for at least $\frac{1}{2}$ in. from the face to give better bond between the stucco and brick. The surface of the brick should be brushed free from all dust, dirt and loose particles, and should be wetted to such a degree that water will not be rapidly absorbed from the stucco, but not to such a degree that water will remain standing on the surface when the stucco is applied.

The composition and placing of the stucco are discussed in Article 80.

**Face Brick with Hollow Tile or Hollow Brick Backing.** — Face brick may be backed with hollow tile or concrete blocks as discussed in Article 20. The facing shall either be bonded to the backing with a row of headers every 16 in. or be attached to the backing with metal wall ties bedded in the mortar joints. Such ties should be spaced not further apart than one foot vertically and two feet horizontally. When metal ties are used the face brick can not be considered as a part of the backing in determining the required thickness of the wall but if brick headers are used the face brick may be included.

Hollow tile backing may be used to decrease the weight in the case of panel or curtain walls supported by a steel or reinforced-concrete frame, to increase the resistance to the passage of heat and moisture, or to reduce the cost in cases where tile backing is cheaper than brick.

Hollow brick of standard brick size may be used to form the inside face of exterior walls the air cells in the brick increasing the resistance of the wall to the passage of heat and moisture.

**Brick Walls Faced with Stone.** — Brick may be used for backing walls which are faced with stone ashlar as shown in Fig. 41. The ashlar should not be less than $3\frac{3}{4}$ in. thick and each stone should be reasonably uniform in thickness but all stones need not necessarily be of the same thickness.

Each block of ashlar should be bonded into the backing, or securely anchored to the backing with metallic anchors, as described in Article 19.

**Frame Walls Veneered with Brick.** — This type of wall should be classed under frame construction and is discussed in Article 28.

**Trim Stone and Terra Cotta.** — Cut stone as described in Article 19 and architectural terra cotta as described in Article 21 are frequently

[1] Recommended Minimum Requirements for Small Dwelling Construction, Building Code Committee of the Department of Commerce.

used as a trim around window and door openings and for belt courses, copings, and cornices.

**Cleaning.** — After the plasterer has completed his work, all surfaces of face brick should be thoroughly cleaned with a 5 per cent solution of muriatic acid. A stiff wire brush may be used to remove spots and stains. After cleaning, the surface should be carefully washed with water to remove all traces of acid.

**Efflorescence.** — Efflorescence is a white deposit which frequently appears on the surface of masonry walls. It is caused by soluble salts, such as calcium and magnesium sulphates, contained in the brick or mortar being dissolved out by water penetrating the brick or mortar and being deposited on the surface of the wall as the water evaporates.

In order for efflorescence to form it is essential that both the water and the salts be present. Efflorescence may be minimized by the selection of materials which contain a minimum amount of the materials causing efflorescence and by keeping water out of the wall. This may be accomplished, in part at least, by using water-repellant mortar; by capping walls with copings with tight joints and arranged to drip free of the wall or to drain toward the roof instead of towards the face of the wall, by effective flashing, by waterproofing the inside of parapet walls, by providing drips for all sills, cornices, and projecting courses, by providing a waterproof layer on top of foundation walls, and by protecting the walls so that rain and water from melting snow cannot enter the wall during construction.

Efflorescence can be removed by washing the wall with a weak solution of muriatic acid and water and subsequent deposits may be prevented to a certain extent by applying a colorless waterproofing compound to the surface. This waterproofing must be renewed at intervals. The only satisfactory method of preventing efflorescence is in the selection of the materials and in proper design.

The following discussion of efflorescence is quoted from Technologic Paper No. 349 of the Bureau of Standards:

The disintegrating effect of efflorescence on masonry has often been pointed out by various authorities, but its importance has probably never been fully appreciated. Efflorescence is more often regarded as merely a disfiguring deposit of salts on the surface. However, an examination of the surface where such deposits occur will sometimes show an appreciable amount of decay if not a deep spalling or crumbling of the masonry.

Effloresence is a growth of crystals on the surface and in the pores of the masonry where a salt solution evaporates. The solvent carrying the salt is probably always water. The source of the salt may be varied, but in most cases it is leached from the masonry walls by water as it slowly percolates through the

pores. No building material is entirely free from water-soluble salts. . . . It may be also caused by salts carried by ground-waters, and the efflorescence frequently seen on the lower courses of buildings is more apt to be due to this cause. Soot which collects on roofs and horizontal parts of masonry always contains a small amount of water-soluble material which may be leached into the masonry by the rains. Buildings near the seashore are often affected in this way by sea salts which are carried through the air by the spray. . . .

The composition of the salts causing efflorescence may be as varied as their source. Any salt that is soluble in water even to a very slight degree may be finally dissolved and leached to the surface under continued damp conditions. Even a part of the calcium carbonate of limestone is sometimes dissolved when water trickles down between the stone facing and the masonry backing. When the solution finds its way to the surface and evaporates, a crust or stalactite may be formed on the exposed surface. Such formations are frequently found on the soffits of masonry arches. . . . As a rule, natural stone may be lower in water soluble matter than artificial products.

The disintegration action of efflorescence is similar to that of frost. When the solution of salts evaporate, the salts are left behind and form crystals. Some of the crystals develop in the pores of the stone and in their growth exert a wedging action which gradually pries small fragments from the surface. This action is far more severe and shows its effects more rapidly than frost. . . . Under continual dampness on walls efflorescence may occur, but all of the crystals will necessarily be on the surface and no decay will ensue. For this reason one frequently finds that the masonry near the ground level is in good condition while at a certain height above the ground a zone of decay is noted. This is evidently due to moisture rising from the ground which keeps the lower part continually damp, but where the damp condition ceases the crystals of dissolved matter form in the pores.

The rapidity of decay from severe cases of efflorescence is proven by the fact that noticeable disintegration sometimes occurs within a year after the structure is completed. Even the densest and strongest materials are not immune to such action, although such materials are usually more resistent to this condition than weak and porous ones. . . .

**Colorless Waterproofing Materials.** — It may be desirable to treat the exposed surfaces of brick walls with colorless waterproofing materials to keep moisture from penetrating the walls and causing dampness, efflorescence, and disintegration. For a discussion of these materials see Article 19.

**Brick Arches.** — Brick arches are used over openings in brick walls, in brick arch floors as shown in Fig. 34*a* and in many other parts of buildings. Various forms of arches are discussed in Article 17.

Brick arches may be constructed of one or more rows of brick on edge with the end exposed as shown in Fig. 34*b* forming a *row-lock arch;* with one or more rows of brick on end with the narrow edge exposed as shown

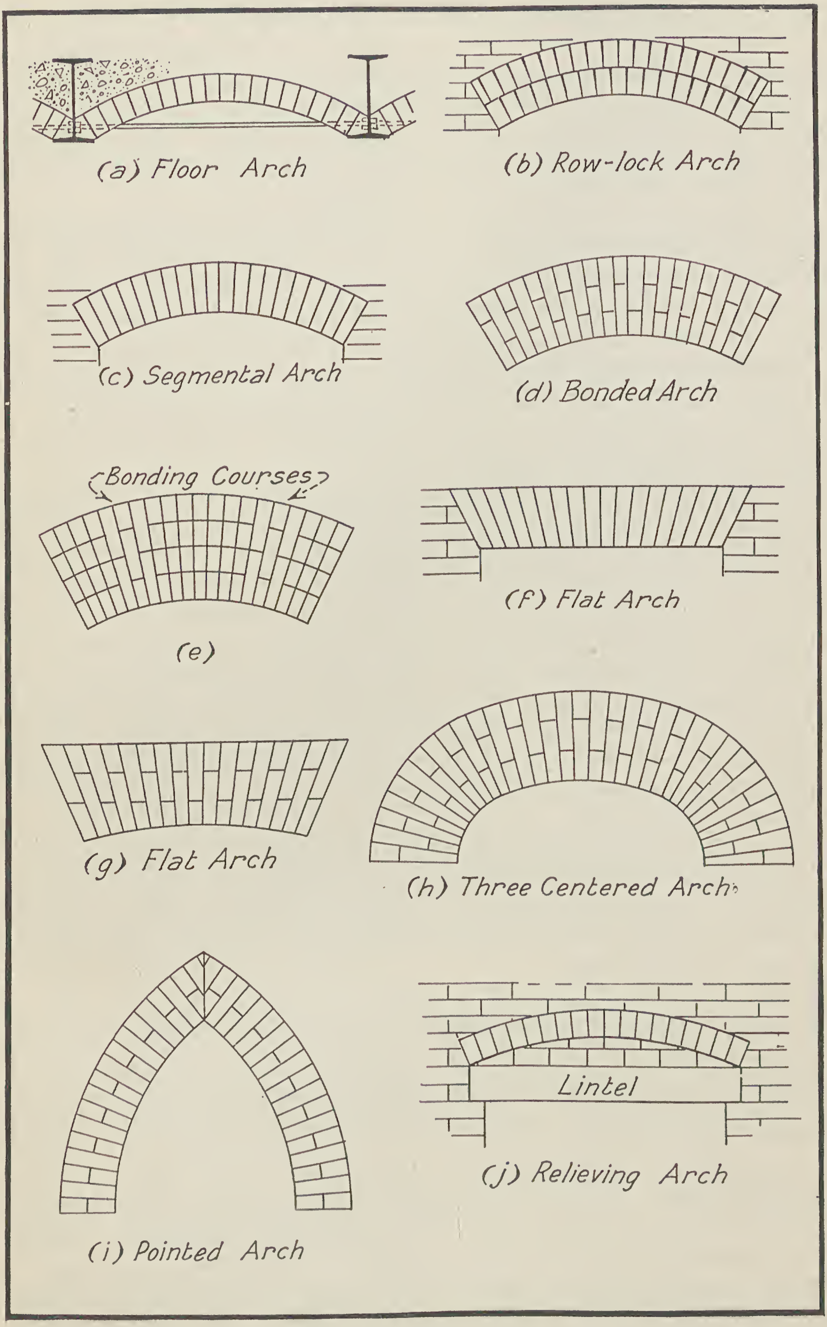



Fig. 34. Brick Arches

in Fig. 34*c*; with the courses forming the arch ring bonded as shown in Fig. 34*d*; or with bonding courses at intervals as shown in Fig. 34*e*.

The bricks may be adjusted to the curvature of the arch by making wedge-shaped mortar joints or by shaping the bricks to fit the spaces which they are to occupy and using joints of uniform thickness. Arches constructed of brick so shaped are called *gaged arches*, as shown in Fig. 34*d*, and *e*. This shaping is accomplished by laying the arch out on the floor and cutting and rubbing the bricks to the proper shape before the work of placing is started. Arches of other types than the row-lock will usually have to be gaged.

Two forms of *flat* or *jack arches* are shown in Figs. 34*f* and 34*g*. Such arches are often supported on concealed lintels in which case they are not true arches.

Brick arches are often constructed over lintels in the backing of brick or stone walls as shown in Fig. 34*j*. These arches are used to take the load from the lintels and are called *relieving* or *discharging arches*.

As previously mentioned, brick arches between steel beams may be used for floors as shown in Fig. 34*a*. Where a flat ceiling is desired a suspended ceiling of plaster or metal lath must be used.

The span of brick arches should not be exceed 8 ft. The thickness should not be less than 4 in. for spans of 5 ft. or less, and 8 in. for spans exceeding 5 ft., and not exceeding 8 ft., but in any case the arch should be proportioned to carry the imposed load. The rise should be at least 1 in. for each foot of span.

The arches should be composed of good, hard, common or hollow brick, solidly bonded by breaking joints, and laid in cement mortar. Suitable skewbacks should be provided to receive the arch. The exposed part of the beams should be properly fireproofed. The remarks concerning tie-rods and cinder concrete filling for tile arches also apply to brick arches.

The weight of brick arches is very great and their use is limited to floors carrying very heavy loads. They have practically gone out of use due to the greater economy of other types of construction such as reinforced-concrete slabs.

## Minimum Wall Thickness

The factors which affect the thickness of masonry walls are discussed in Article 17. For hollow brick walls see pp. 190–192 inc.

The recommendations of the Building Code Committee of the Department of Commerce for brick walls are as follows

Wall thicknesses specified are nominal, referring to the minimum thickness obtainable with building units of standard size. It is common in some parts of

the country to designate brick walls as 9, 13, and 17 in. in thickness, but with the standardization of brick and tile sizes now becoming general, it is more correct to express the dimensions as 8, 12, and 16 in.

**Lateral Support.** — Solid brick walls shall be supported at right angles to the wall face at intervals not exceeding eighteen times the wall thickness in the top story or twenty times the wall thickness elsewhere. Such lateral support may be obtained by cross walls, piers, or buttresses, when the limiting distance is measured horizontally, or by floors when the limiting distance is measured vertically. Sufficient bonding or anchorage shall be provided between the wall and the supports to resist the assumed wind force, acting in an outward direction. Piers or buttresses relied upon for lateral support shall have sufficient strength and stability to transfer the wind force, acting in either direction, to the ground. When walls are dependent upon floors for their lateral support, provision shall be made in the building to transfer the lateral forces resisted by all floors to the ground.

**Thickness of Exterior Walls Other Than in Skeleton Construction.** — The thickness of solid brick bearing walls shall be sufficient at all points to keep the combined stresses due to live and dead loads for which the building is designed within the limits prescribed.

The minimum thickness for solid brick exterior bearing or party walls shall be 12 in. for the uppermost 35 ft. of their height, and shall be increased 4 in. for each successive 35 ft. or fraction thereof measured downward from the top of the wall; except that the top story exterior bearing wall of a building not exceeding three stories or 40 ft. in height, or the wall of a one-story commercial or industrial building may be 8 in. thick, provided that such 8-in. wall does not exceed 12 ft. unsupported height and that the roof beams are horizontal; and except that exterior solid brick bearing walls of one and two family dwellings may be 8 in. thick when not more than 30 ft. in height. When gable construction is used for such dwellings, an additional 5 ft. is permitted to the peak of the gable.

Where solid brick exterior bearing or party walls are stiffened at distances not greater than 12 ft. apart by cross walls, or by internal or external offsets or returns, at least 2 ft. deep, they may be 12 in. thick for the uppermost 70 ft., measured downward from the top of the wall, and shall be increased 4 in. in thickness for each successive 70 ft. or fraction thereof.

The minimum thickness of solid brick exterior nonbearing walls shall be 12 in. for the uppermost 70 ft. of their height, and shall be increased 4 in. for each successive 35 ft. or fraction thereof, measured downward from the top of the wall, except that the top story wall of a building not exceeding three stories or 40 ft. in height, or the wall of a one-story commercial or industrial building may be 8 in. thick, provided that such 8-in. wall does not exceed 12 ft. unsupported height, and that the roof beams are horizontal; and except that solid brick nonbearing walls of one and two family dwellings may be 8 in. thick when not more than 30 ft. in height. When gable construction is used for such dwellings an additional 5 ft. is permitted to the peak of the gable.

**Brick Fire Walls.** — Solid brick or fire walls shall be not less in thickness than required for exterior bearing walls of corresponding height, but not less than 12

in., except that solid brick fire walls for buildings of residential occupancy shall be not less than 8 in. thick for the uppermost 20 ft. of height and shall be at least 12 in. thick for the remaining lower portion. No 8-in. fire wall shall be broken into, subsequent to building, for the insertion of structural members.

Party walls which function also as fire walls shall conform to requirements for fire walls.

**Fire Division Walls.** — Fire division walls of solid brick shall be not less than 8 in. thick.

**Nonbearing Partitions.** — For nonbearing partitions, materials meeting the ordinary accepted local standards for the purpose may be used.

Brick nonbearing partitions shall be not less than $3\frac{3}{4}$ in. thick for a height not exceeding 12 ft. between floors or floor beams and for a length not exceeding 20 ft. between vertical supports.

**Panel and Inclosure Walls.** — Panel walls in buildings of skeleton construction shall be not less than 8 in. thick if of solid brick, hollow tile, concrete block or tile, plain concrete, or hollow walls of brick. Inclosure walls shall be not less than 8 in. thick nor less in thickness than one-twentieth the horizontal distance between anchors.

**Foundation Walls.** — Foundation walls for solid-wall construction shall be of stone, solid brick, concrete (plain, rubble, or reinforced), or concrete block. Solid brick foundation walls and those of concrete block or coursed stone shall be not less in thickness than the walls immediately above them and in no case less than 12 in. thick, except that when the inclosure is not excavated, they may be 8 in. thick if included within the allowable height of 8-in. walls.

When the stresses due to earth pressure and superposed building load exceed the maximum working stress specified for brick masonry, and the additional stresses are not otherwise provided for, the wall thickness shall be increased to bring them within these limits.

It has been customary to require that foundation walls be made thicker than those immediately above them. The committee does not believe this necessary in all cases. A foundation wall acts both as a bearing wall and a retaining wall. As a bearing wall it has few or no openings compared to the walls above it, and its unit compressive stresses are usually lower. As a retaining wall it owes practically all its stability to the weight resting upon it, and except in very thin walls the addition of 4 in. of thickness increases its resistance to side thrust very little. Where analysis of the forces acting upon it discloses combined stresses greater than those allowed or where such forces may cause tension in the masonry, the thickness should be increased.

Foundation walls should be waterproofed with cement plaster, or by other effective means, and unless surrounded by sand or gravel, or otherwise naturally drained, should have open tile drains around the footings on the outside discharging into an outfall at a lower level.

All foundation walls shall extend below the level of frost action.

**Chases and Recesses.** — For the requirements concerning chases and recesses see Article 17.

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## ARTICLE 19. STONE MASONRY

Stone masonry and dressed stone facings are extensively used in exterior walls where appearance is an important factor. Concrete has largely replaced stone for foundation walls but when stone can be obtained locally at low cost foundation walls may be constructed of stone.

### Formation of Building Stones, Quarrying, and Cutting

**Geological Classification of Building Stones.** — The rocks used for building stone are divided into *igneous* and *sedimentary rocks* according to the *method of formation.*

*Igneous rocks* are those formed by the solidification of molten rock which has been forced up through fissures in the earth's crust. If this solidification occurred below the surface of the earth the rock is called *plutonic* but if it occurred on the surface *volcanic rock* is formed.

*Sedimentary rocks,* with minor exceptions, are those which have been formed by the deposition in water of material carried by water in suspension or solution, and the subsequent consolidation and hardening of this material by pressure or other agencies. A characteristic feature of sedimentary rocks is the layers or strata into which they are divided. The process of deposition has rarely been continuous but variations have occurred in the velocity of the deposition current and in the size and composition of the material carried in suspension and in the composition of material in solution. These variations have resulted in the division of the deposits into layers which differ somewhat from each other. The dividing surfaces between layers are called *bedding planes.* On account of this division into layers or strata, many sedimentary rocks are also called *stratified rocks* but some may be treated as free-stones without reference to grain.

*Metamorphic rocks* are sedimentary or igneous rocks which have undergone marked changes under the action of heat, pressure, and chemical agencies. These changes may be in the physical structure of the rock, in its texture, or in its chemical composition.

**Chemical Classification of Building Stones.** — Building stones are divided into three classes according to their chemical composition as follows: *Argillaceous stones* in which alumina ($Al_2O_3$) is the most important constituent; *calcareous stones* in which the most important con-

stituent is calcium carbonate ($CaCO_3$); and *siliceous stones* which are composed chiefly of silica ($SiO_2$).

The most common argillaceous stone is slate; the most common calcareous stones are limestone and marble; and the most common siliceous stones are sandstone and granite.

**Formation and Properties of Building Stone.** — The most important building stones are granite, sandstone, limestone, marble and slate.

*Granites* are plutonic igneous rocks with coarse crystalline structure, composed chiefly of quartz, feldspar, and usually some mica. The colors of granites are gray, black, white, green and red. Where granite is at the surface of the earth it has been exposed by the weathering down of overlying material. Granite is a hard, durable stone suitable for use in any part of a structure but particularly suitable for base courses, steps, and door sills on account of its resistance to weathering action and wear. Due to its extreme hardness granite is expensive to work into shape.

*Lava* is a volcanic igneous rock which is not usually suitable for building purposes but some deposits have yielded fairly good stone.

*Sandstones* are sedimentary rocks formed by the consolidation of beds of sand which have been deposited by water carrying the sand in suspension. The consolidation has been due to pressure exerted by overlying material and to a cementing material which may be clay deposited with the sand, or silica, lime carbonate, or iron oxide carried in solution by water which later penetrated the beds, the dissolved substances being deposited around the sand grains and cementing them together. In general the sandstones with silica as a cementing material are best, followed by clay, iron oxide, and lime carbonate, arranged in the order of their desirability. Sandstones are found in various colors such as white, gray, red, blue and brown. Some sandstones are very hard and durable while others are of little value so a careful investigation should be made before using any stone. Many sandstones are durable and still soft enough to be worked into shape at a reasonable cost, others are very hard and expensive to work but make very satisfactory sills, steps and flagstones where a large amount of dressing is not required, and others are very easily worked but are not durable.

*Limestones* are sedimentary rocks formed chiefly by the accumulation of shells on a sea bottom. Some limestones show fossils but in others all traces of their origin have been destroyed by the fine grinding to which the shells were subjected after their deposition at the sea bottom. The shell fragments were probably cemented together by a chemical deposit of calcium carbonate from solution. Limestone when pure is calcium carbonate but in commercial limestones, magnesia, silica, and iron oxides are found in small amounts. The colors available are gray, buff and

white. Good limestones are sufficiently durable for building purposes, but may be soft enough to be easily worked into shape. Oolitic limestone quarries in Indiana yield a stone which can be quarried and worked into shape so cheaply that in spite of freight charges this stone is shipped to all parts of the United States in competition with local stones.

*Marbles* are metamorphic limestones which have become crystalline through the action of heat and pressure. In the stone trade, any limestone which can be polished is classed as marble. The chief use of marble is for the exteriors of monumental buildings and on the interior of high class public buildings.

*Slate* is a metamorphic rock formed from sedimentary deposits of siliceous clay which have collected on ancient sea bottoms and have been subjected to heat and pressure. The pressure to which the deposits have been subjected causes cleavage planes which bear no relation to the original bedding planes. The most common color for slate is a bluish gray but black, green, red, and purple slates are plentiful. Slate is used for roofing, walls, flagstones, floor tiles, and blackboards.

**Quarrying.** — Quarrying consists of separating rough blocks of stone from rock formations. In small quarries the work may be done entirely by hand tools with more or less assistance from explosives but in the larger quarries machines are used. Explosives are used to a very limited extent on account of the waste they cause. Their chief use is in removing the overburden to expose the solid stone.

The character of the rock formation has an important bearing on the quarrying methods. The stratified sandstones and limestones have been deposited in layers as explained. The surfaces of contact of adjacent layers are called *beds*. In quarrying, advantage is taken of these beds which offer planes along which separation is easily accomplished. The beds may be so close together that the stone is only useful for *flagging* or they may be so far apart or so indistinct that they are of little assistance in quarrying but the stone may be of greater value in spite of this fact for the size of the stones is then not limited by the beds.

The unstratified rocks such as granite do not lie in separate layers but have a massive structure and surfaces of separation have to be made by artificial means. Such rocks may split more easily in one direction than in another.

Both stratified and unstratified rock formations may be divided by *seams* running in any direction. The presence of these seams may be an advantage in quarrying or a disadvantage on account of the limit they place on the size and shape of the pieces removed. These seams may be very conspicuous and offer a distinct surface of separation, they may not be discovered until considerable work has been done

on a stone, or they may even cause failure after a stone has been placed in a structure. *Streaks* may occur in stone without reducing its strength.

If a formation is badly broken up by beds and seams the rock may be removed with crow bars, picks, and wedges but *dimension stones* are difficult to secure under these conditions excepting in small sizes.

Building stone is removed from the quarry in rough blocks which are later cut into pieces of the desired size. In separating the rough blocks from the rock formation the rock may be broken along a line by drilling a row of closely spaced holes by hand or machine along that line and split-

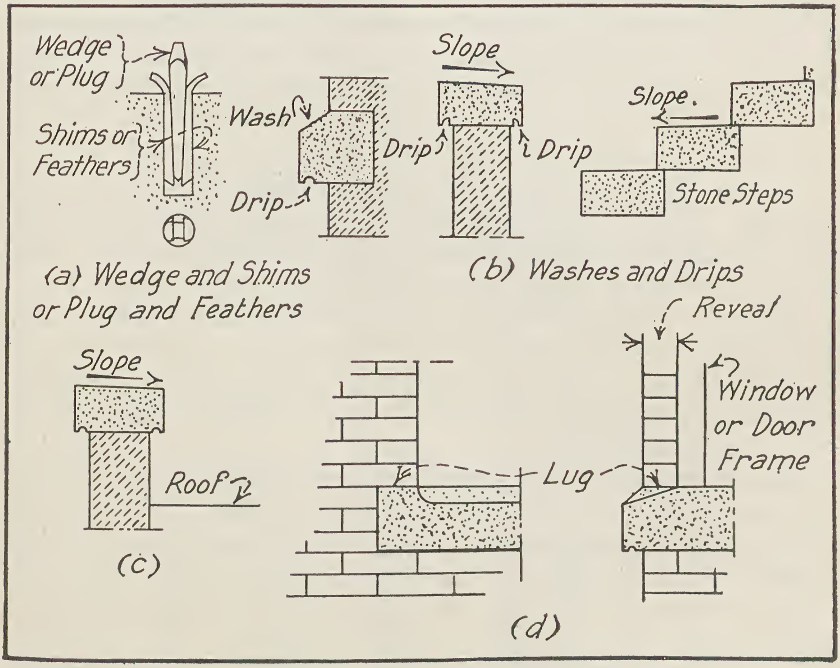


Fig. 35. Wedge and Shims, Washes, and Drips

ting the rock between the holes by means of *plug and feathers*. The plug is a steel wedge and the feathers are wedges rounded on one side to fit the outline of the hole and flat on the other to form a surface over which a wedge is driven as shown in Fig. 35*a*. Plug and feathers are placed in each hole and the plugs are gradually driven in with a hammer, driving each plug a little at a time and in succession. By continuing this operation a force of sufficient intensity to split the rock is developed. In stratified stones the blocks are split along a plane perpendicular to the bed which gives a natural surface of separation. In unstratified rocks

plug and feathers may be used along two planes at right angles to each other. Plug and feathers are also known as *wedge and shims.*

The splitting is sometimes accomplished by wooden plugs driven in the holes and soaked with water. The water causes the plugs to expand and exert a force which splits the rock.

Channeling machines are widely used for quarrying. These machines cut narrow channels along the face of the block to be cut out. These channels are cut vertically and may be as deep as 10 or 15 ft. The blocks are separated from the quarry ledge at a bedding plane, or they may be split along a horizontal plane by drilling holes and using wedges.

The plug and feathers method may be used on any kind of stone and is the method used in granite quarrying. The channeling method is not suitable for granite but is the method commonly used for quarrying limestone, marble, and sandstone except the harder varieties where the plug and feather method is more suitable.

In many localities stones found loose in the field are used for building purposes. These are called *field stones.* They may be used in the shape they are found or they may be split or shaped with the hammer. *Cobble stones,* which may be defined as large pebbles, are used in the same way.

**Cutting.** — The process of *cutting* or *dressing* consists of separating, shaping and finishing building stones of the desired size and finish from the rough blocks produced by the quarry. These blocks are divided by splitting with or without the assistance of holes drilled along the line of separation, or by sawing.

Many limestones and sandstones are sawed without difficulty, so for such stones this process is used exclusively, but granite and some of the harder sandstones are split unless the stone is to be used for ashlar with a bushed, honed or polished surface finish in which case sawing may be cheaper on account of the greater ease with which the sawed surface is finished.

Round balusters and columns may be cut by hand but they are usually turned in lathes. Moldings may be cut by hand or by machines called planers. Most stones used for building purposes can be sawed and practically any work which can be done by hand can also be done by machine.

Stones of large size or special shape or any stone for which all dimensions are specified in advance, other than finished cut stone, are called *dimension stones.*

**Washes and Drips.** — The exposed top surfaces of cornices, copings, belt courses, sills, steps, platforms and other stones which should shed water are provided with sloping surfaces called *washes.* See Fig. 35*b*.

Projecting stones such as cornices, belt courses, and sills are provided

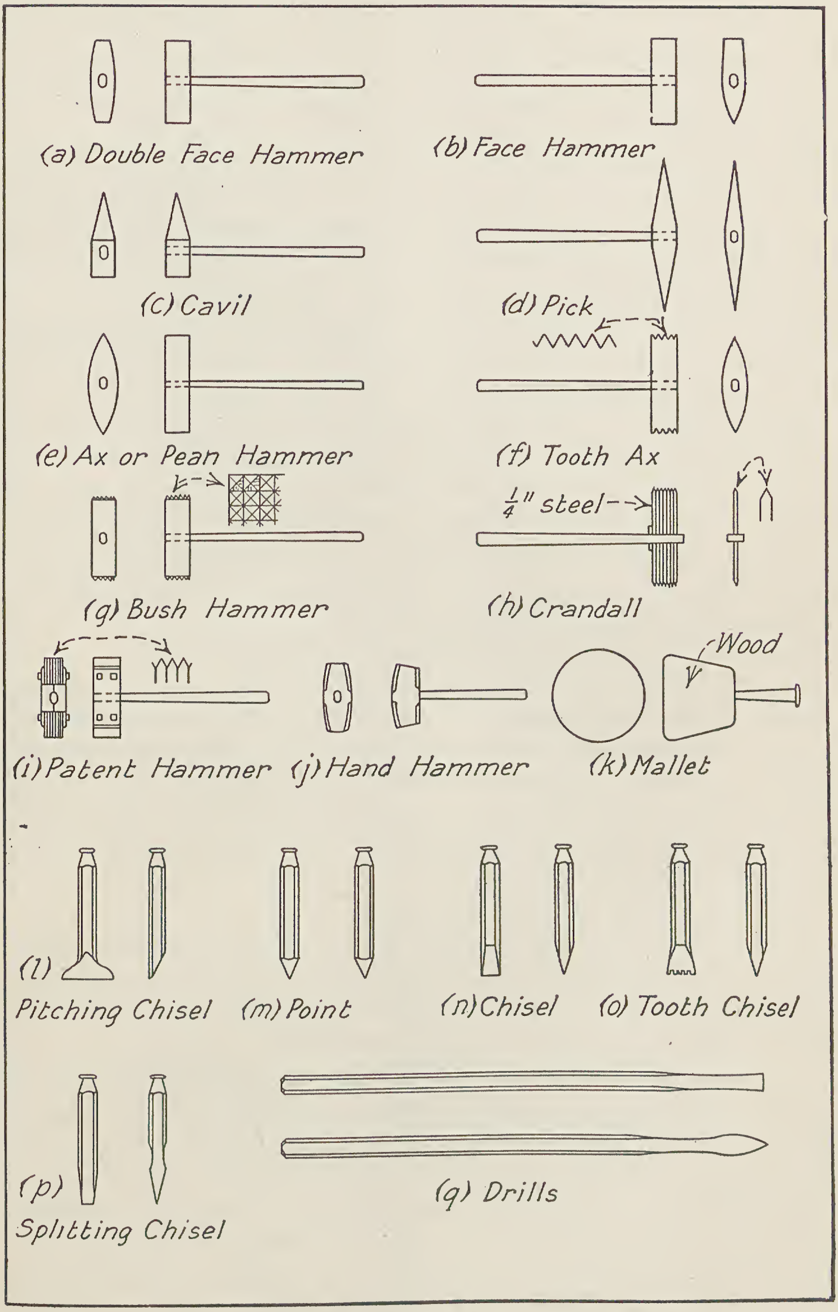


Fig. 36. Hand Tools used in Stone Cutting and Finishing

with a groove or channel on the under surface of the projection and near the outer edge. This groove is called a *drip* for it causes water to drip from the lower edge of the projecting stone rather than follow along the surface of the wall. Drips should be at least $\frac{1}{2}$ in. wide by $\frac{1}{4}$ in. deep, but larger drips are better if they can be provided. See Fig. 35*b*.

The stonework will usually be soiled or streaked where the washes pitch toward the face of the stone work. For this reason it is desirable that copings pitch toward the roof and that the water be drained off of projecting stones rather than allowed to run over the face of the stone even though it drips from the lower edge. See Fig. 35*c*.

Where other work is built on stones provided with a wash it will usually be necessary to cut *raised seats* and *lugs* on the stones to form level beds for the work which is built on them. See Fig. 35*d*.

**Surface Finish.** — There are various methods of finishing the exposed surface of building stone. The finish which is suitable for a given case is governed by the kind of stone and the manner in which it is used and varies from the rough face formed in quarrying to the highly polished face often used on marbles and granites. The hand tools used in finishing are described in Vol. VI of the *Transactions* of the American Society of Civil Engineers and are shown in Fig. 36.

Tools used with pneumatic hammers are shown in Fig. 37.

A *quarry face* is a face which is on a stone when it comes from the quarry. It may be formed by the quarrying operations or may be due to a natural seam in which case it is called a *seam face.* Quarries producing seam-face stone are traversed in all directions by natural seams forming relatively small blocks of stone of irregular shape and size. Seam faces are often highly colored by deposits from mineral laden waters which have penetrated into the seams.

A *split face* is formed by splitting a rock.

A *rock* or *pitch face* is one in which the four exposed edges forming the *arris* are clearly defined by a line beyond which the rock is cut away with a broad pitching chisel so that the edges are approximately straight and lie in a single vertical plane as shown in Fig. 38*a*.

A *pointed finish* is one which has been dressed or finished with a pointing chisel until the general surface is flat but rough due to the depressions left by the pointing chisel as shown in Fig. 38*b*. There are three grades of pointing, *fine*, *medium* and *coarse* or *rough*, the grade depending upon the distance between the depressions. Pointing may be done by hand or by machine, the machine pointing generally being more regular. The crandall is used to produce a rough-textured surface somewhat resembling a pointed face where a much finer and more evenly tooled finish is desired than can be secured by pointing. See Fig. 38*i*. The

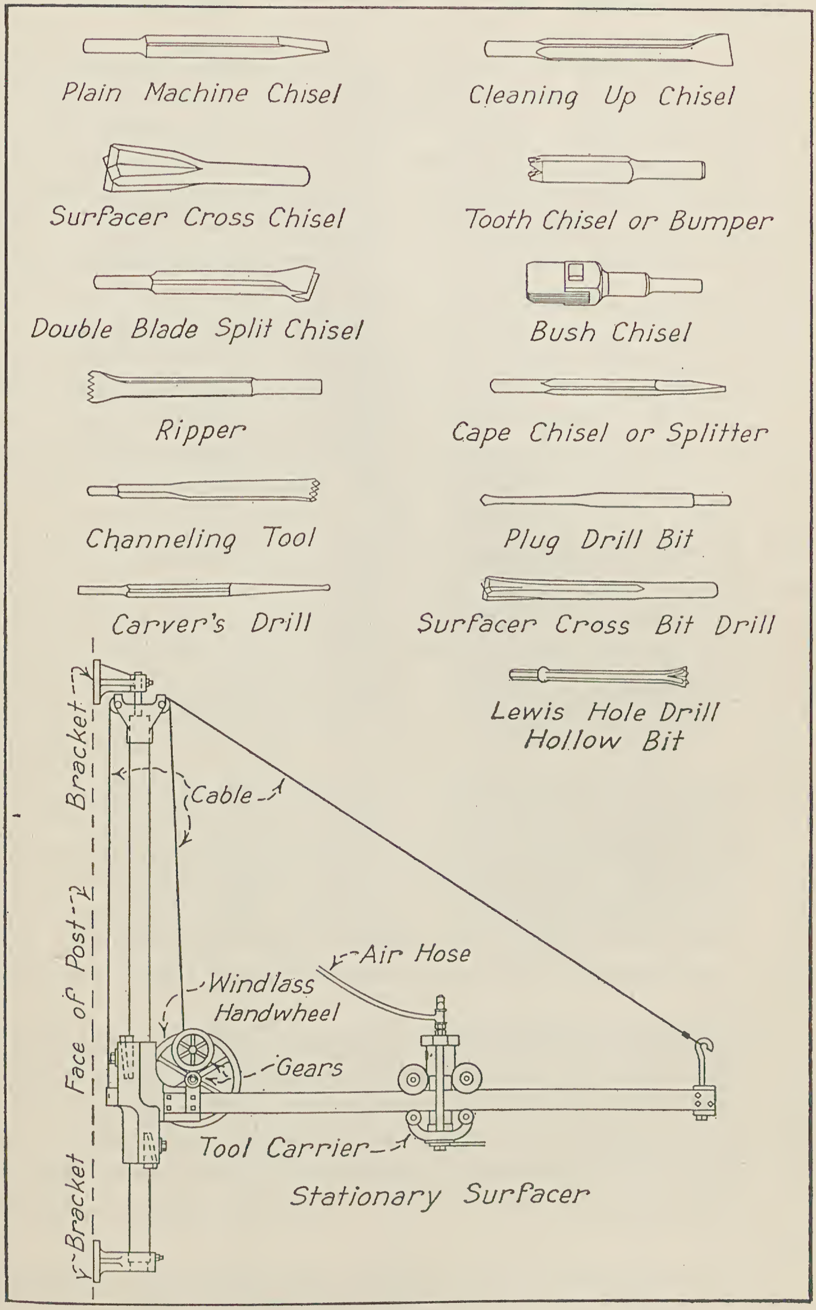


FIG. 37. Pneumatic Tools used in Stone Cutting and Finishing

tooth axe produces a courser though similar effect to that of the crandall.

A *hammered finish* is one which has been dressed or finished with hammers of various kinds until the general surface is flat but rough due to the hammer marks. Surfaces which are to have a hammered face are first reduced to a fairly even surface by pointing. The *pean-hammered face* as shown in Fig. 38*c* is produced by finishing with a pean hammer, forming a surface with parallel lines, more or less regularly spaced. The *bush-hammered face* shown in Fig. 38*d* is produced by finishing with a bush hammer. The *patent bush hammer* shown in Fig. 36 has a head with an opening about $\frac{7}{8}$ in. wide in which are bolted sets of 4, 6, or 8 cutting blades with parallel edges, giving 4, 6, or 8 cuts or bats in $\frac{7}{8}$ in. Surfaces which are to be finished with this hammer are first finished with a pean hammer operated in both directions to remove all trace of the pointing. The *four-cut finish* is produced by following the pean hammer with a patent hammer with four blades. The *six-cut finish* is produced by following the four-cut finish with six blades in the hammer. The *eight-cut finish* follows the six-cut finish and the process is sometimes continued forming ten and twelve-cut finishes but these finishes are rarely used on building stone. Pneumatic surfacing machines may be used to produce the same finish as the hand hammers just described, especially for the larger surfaces. Sawed surfaces may be given a hammered finish without the preliminary work of pointing which is necessary on rough surfaces. Finishes produced by the parallel blades of the patent hammer appear to be uniformly corrugated but the hammer marks are not necessarily continuous. The marks are usually made vertical on wall surfaces; but on molded surfaces they are made parallel to the direction of the molding and on the top surfaces of sills, steps, washes, and copings they are made perpendicular to the length. Hammered faces of one form or another are commonly used on granite and the harder limestones and sandstones but are not suitable for the softer varieties of limestone.

The *tooled finish* shown in Fig. 38*e* consists of parallel corrugations or bats produced by hand with a chisel about 4 in. wide. The tooled finish shown in Fig. 38*f* is produced on a planer with a corrugated tool. These finishes are designated as 4 *bats* to the inch, 6 bats to the inch, etc., depending upon the number of corrugations or tool marks to the inch. Tool marks are given the same direction as the hammer marks just described.

The *drove* or *boasted finish* shown in Fig. 38*g* is similar to the hand-tooled finish but it has several series of corrugations on the width of the face instead on one group in which the corrugations are more or less continu-

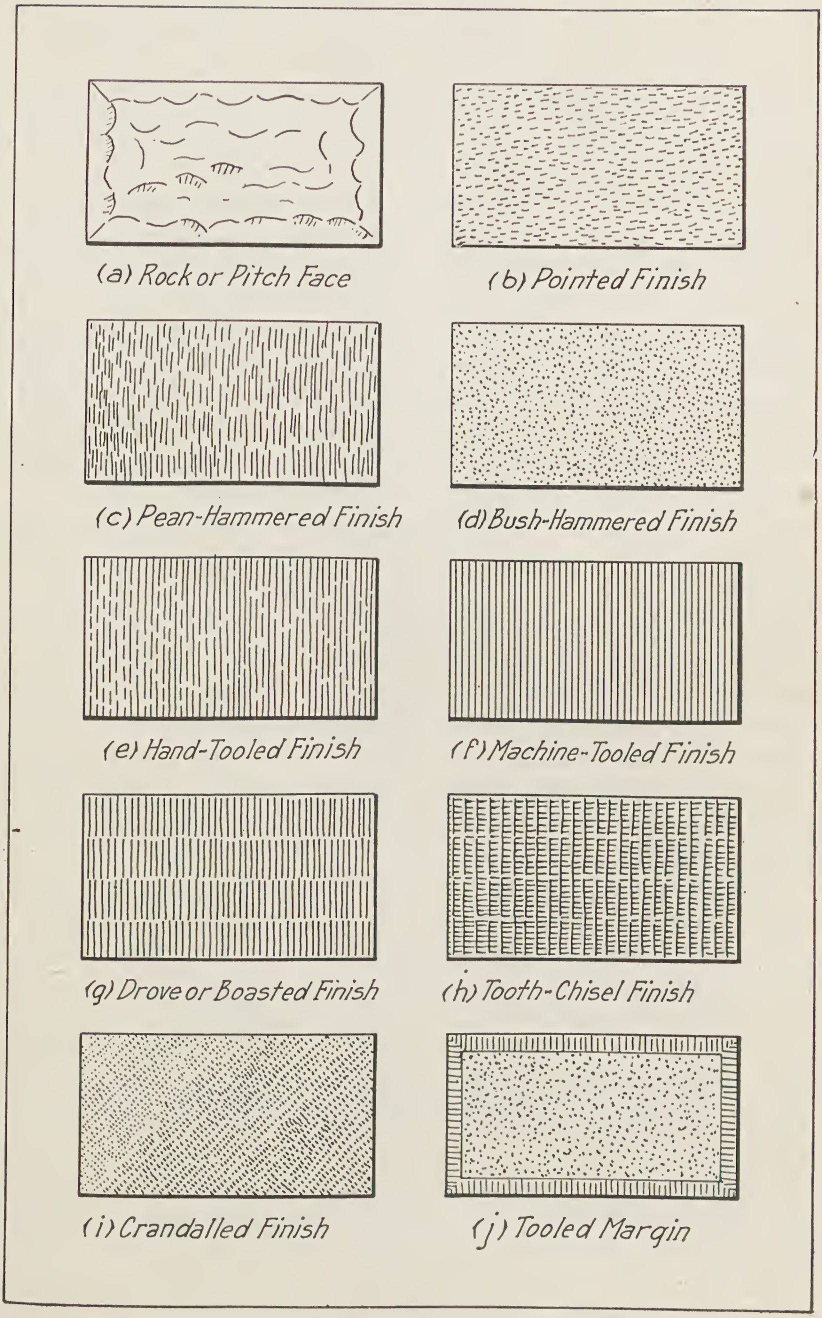


FIG. 38. Stone Finishes

ous. The drove finish is produced with a chisel about 2 in. wide known as a drove or boaster. The tool marks are often made diagonally.

The *tooth chisel finish* shown in Fig. 38*h* is similar to the hand-tooled and drove finishes but has fine corrugations at right angles to the corrugations of these finishes. The two sets of corrugations are produced by using a toothed chisel instead of the plain chisel or drove.

A *sawed finish* is the surface produced by the saws in cutting a stone to size. The marks of the saws are visible.

A *smooth finish* is produced by planers without hand work other than the removal of objectionable tool marks.

*Rubbed* and *honed finishes* are produced by grinding or rubbing a sawed or pointed surface by hand or machine, small surfaces and moldings usually being finished by hand. The grade of rubbing is determined by the extent to which this process is carried. Coarse rubbed finish will show small scratches but a honed finish gives a smooth dead surface practically free from scratches.

A *polished finish* is secured by polishing surfaces which have been previously honed. Granite and marble will take and hold a polish but most other stones will not.

The *margin* or *border* of a stone may have one type of finish and the remaining area may be another type as shown in Fig. 38*j* which shows a tooled margin with the remainder of the surface bush-hammered. Stones finished in this manner are called *drafted stones.*

**Selecting Surface Finish.** — The proper finish to be used depends upon the type of masonry, kind of stone, its position and use in the building, the architectural effect desired, the atmospheric conditions, and the money available.

All of the types of finish just described may be used on granite and marble, and with the exception of polishing they may be used on sandstone and limestone. Limestone which can be polished is usually classed as marble. The hammered finishes are suitable only for the harder sandstones and limestones for on the softer stones the ridges will not stand up but will break off leaving a bruised face. These finishes are often called *hard stone finishes* for they are not suitable for soft stone. The tooled finishes are similar to the hammered finishes and are more suitable for soft stones.

In selecting a finish, the type which will give the desired results for the least cost would naturally be used. Very satisfactory results are often produced with quarry, seam, a split faced rubble masonry at low cost.

In general rubble masonry will be quarry faced, squared stone masonry will be quarry faced or pitched faced, and ashlar or cut stone masonry will have a pointed or hammered face if of granite and a sawed, smooth,

or rubbed face if of limestone or sandstone. Marble will usually be rubbed or honed for exterior use and either honed or polished for interior use. A quarry face or pitch face may also be used for ashlar.

The hammered face of granite will usually be six-cut but four-cut finish above the second story looks about the same from the ground as six-cut.

On account of the ease in cleaning, polished surfaces are often used for the base courses and other parts which may be splashed with mud by passing vehicles and for lower stories where exposed to a smoky atmosphere. The fine finishes keep clean longer than the coarse finishes.

The sawed finish is the cheapest finish for limestone and sandstone, except the harder grades. The standard finish for Indiana limestone is the smooth finish. Machine tooled finish is usually four, six, or eight bat to the inch. Two-bat tooling may be used on large scale work and ten-bat tooling when a specially fine tooling is desired. Hand-pointed finishes are often used on limestone as well as on sandstone and granite.

The finer finishes are more suitable for use on interior surfaces than the coarser finishes, but on the exterior the finer finishes will not show if used above the first story so the cheaper finishes are more suitable.

**Quality of Building Stone.** — The quality of a building stone is determined by its durability, strength, workability, and appearance.

To be durable, a building stone must be capable of withstanding temperature changes, alternate freezing and thawing, the chemical action of acids from the atmosphere and other sources, and abrasion in the case of steps, door sills, and floor slabs.

The harmful effects of temperature changes are due to the different coefficients of expansion of the minerals of which the stone is formed and to the unequal exposure of different parts of the stone which cause internal stresses that tend to break the stone apart.

When water which is present in the pores of a building stone freezes the resultant expansion exerts very powerful forces which tend to disrupt the stone. The following comments on frost action are abstracted from Technologic Paper No. 349 of the Bureau of Standards by D. W. Kessler and W. H. Sligh:

> Freshly quarried blocks may contain a considerable amount of water called *quarry sap;* such blocks are frequently disrupted in winter because the stone does not have sufficient tensile strength to resist the expansive force of ice forming in the pores. Whether a stone will rupture in this way depends mainly on the amount of pore space and the cohesive strength. There is some evidence that an open texture — that is, one which permits an easy flow of water, will prove more resistant to frost action. In general, high strength and low porosity or absorption are favorable to frost resistance but apparently a stone of low strength and high porosity may show good resistance to frost if it has an open texture.

A method which consists in crystallizing a salt in the pores of a stone is sometimes used for simulating the effects of frost action. This is done by soaking or boiling the stone in a salt solution and then drying it to cause the salt to crystallize. The crystals in forming cause internal stresses in the stone somewhat like the action of frost. The salt which has been mostly used for this purpose is sodium sulphate. The action of this salt is very severe causing many stones to be disintegrated by a few repetitions of the operation. While the test is assumed to produce only a physical action there is evidence of chemical action as well.

This is known as Brard's Test. Such tests are not always dependable. Actual freezing and thawing tests carried on in the laboratory may give very good comparative indications of the frost resistance of stones.

Rain in falling through the atmosphere of cities collects small amounts of acids, such as carbonic or sulphuric acid, which result from the burning of coal and from industrial processes. This rain water tends to dissolve stone masonry but the action is very slow. Limestone is affected more than most other building stones according to Technologic Paper No. 349 of the Bureau of Standards.[1]

The surface solution goes on at such a slow rate that it is not usually noticeable except on delicately carved parts which are freely exposed. In general, this action is advantageous, since it tends to keep the surface fresh and clean. Sometimes it will be noted that limestone buildings appear cleaner than other kinds of masonry. Those limestones of a dolomitic nature are not so readily dissolved by acids and hence do not weaken from their course at the same rate as those which are mainly calcium carbonate.

The best means for determining the durability of a stone is by an examination of the parts of the quarry which have been exposed for a long period of years. An examination of buildings in which the stone under consideration has been used will also indicate its durability if the stone has been in place for a long period of years.

Practically all stones which would be considered for building purposes have sufficient compressive strength to carry the loads which might be placed upon them but due to unequal settlement, improper bedding, temperature changes, wind stresses, etc., stones may be subjected to stresses which require a high flexural strength.

High strength is always a desirable characteristic aside from its advantage in better resisting the usual stresses. In general, high strength denotes durability. A strong material is less apt to become defaced in those parts of a structure which are subject to accidental injury. All arises which are within the reach are apt

[1] Physical Properties of the Principal Commercial Limestones in the United States, by D. W. Kessler and W. H. Sligh.

to become chipped, and badly marred in appearance. Weak stone is readily defaced in this way and often suffers defacement during construction. Delicate carvings in order to withstand accidental injury require considerable strength.[1]

Many stones which are satisfactory for ordinary building purposes cannot be used for steps, door sills and floors because of their low resistance to abrasion.

Stones which are durable, strong and attractive in appearance may not be suitable for building purposes because of the labor required to work them into the desired shapes. Some stones which would not be suitable for ashlar may be satisfactory for rubble or squared-stone masonry which require a relatively small amount of labor in shaping. Stones which are soft enough to work readily are frequently not durable. Ornamental work such as moldings and carvings requires a stone with even grain which is free from seams and other defects. Stones which can be easily worked in any direction and are free from stratification are called *free-stones.* Stones which have been recently quarried may contain a considerable amount of water known as *quarry sap.* They are more easily worked when they are *green* than after they have *seasoned* and the quarry sap has drained out and evaporated.

The architectural treatment of a building may require stone of a certain color, so stones which may be suitable in other respects may not be satisfactory in specific cases.

In some cases, the fire resistance of a stone may be an important consideration. No building stones will stand very high temperatures. This is particularly true when the heated stone is subjected to a stream of water as is frequently the case in burning buildings. On account of its low resistance to fire the use of stone for interior piers, caps, and bond stones is sometimes prohibited,[2] but this practice is probably too severe.[3]

Building stones may be arranged in the order of their fire resistance about as follows: Fine-grained sandstone with a silica binder; fine-grained granite or oolitic limestone, ordinary limestone, coarse-grained granite, marble. Limestone fails by calcination at a relatively low temperature.

### Stone Masonry

In classifying stone masonry it is necessary to take into account the degree of refinement used in shaping the stones, the way the face stones are arranged in the wall, and the surface finish of the stones.

[1] Technologic Papers of Bureau of Standards, No. 349.

[2] Recommended Building Code of National Board of Fire Underwriters, Sec. 22.

[3] Recommended Minimum Requirements for Masonry Wall Construction, Report of the Building Code Committee of The Department of Commerce, p. 50.

There are no accepted standards for classification, but in general the crudest type of masonry, constructed of stones with little or no shaping, is called *rubble*, and the highest type, constructed of stones accurately shaped so as to make thin joints possible, is called *ashlar*. Between these two extremes there are various degrees of refinement in shaping the stones and many ways of arranging them in the wall. The most common classification divides masonry into *rubble, square-stone masonry*, and *ashlar* according to the care used in shaping the stones, and into *range, broken range*, and *random* according to the arrangement of the stones in the wall. The latter classification does not apply to rubble. Rubble is classed as *coursed* and *uncoursed.* Ashlar is also called cut stone.

There is no definite line of demarkation between ashlar and squared-stone masonry or between squared-stone masonry and rubble. When stratified stone is used, the horizontal joints of rubble may be as narrow and as uniform as those of squared-stone masonry and the distinction between the two classes would lie in the vertical joints. If the work done on such stone consists only of knocking off loose rock or sharp corners rubble would probably result, but if the stone is shaped to give a uniform vertical joint squared-stoned masonry would be produced. If the end joints are not vertical but are uniform in thickness the class of work would be the same as that on squared-stone masonry but such masonry could not logically be placed in that class because of the shape of the stone.

In some cases the joints are as thin as ashlar joints but the end joints are not vertical. Such masonry should probably be classed as ashlar. If the stones are irregular in shape without parallel faces and are shaped to fit the spaces they are to occupy the joints may be neither vertical nor horizontal. Such masonry is classed as *polygonal masonry* on account of the shape of the face of the stone. In this type of masonry the stones are sometimes accurately cut with joints as uniform and as thin as in ashlar. Often the stones are only roughly shaped and the joints are not uniform in thickness. This type of masonry is often called *mosaic rubble.* The Building Code Committee of the Department of Commerce recommends the following classification:[1]

*Ashlar masonry.* — Masonry of sawed, dressed, tooled, or quarry-faced stone with proper bond.

*Ashlar facing.* — Sawed or dressed squared stones used in facing masonry walls.

*Random ashlar facing.* — Sawed or dressed squared stone of various sizes properly bonded or fitted with close joints used for the facing of masonry walls.

*Coursed rubble.* — Masonry composed of roughly shaped stones fitting approximately on level beds and well bonded.

[1] Recommended Minimum Requirements for Masonry Wall Construction.

*Random rubble.* — Masonry composed of roughly shaped stone laid without regularity of coursing, but fitting together to form well-defined joints.

*Rough or ordinary rubble.* — Masonry composed of unsquared or field stones laid without regularity of coursing.

Squared-stone masonry laid in regular courses with the stones roughly squared with a hammer is sometimes called *block-in-course* masonry or *hammer-dressed ashlar*.

**Arrangement of Courses.** — In *range masonry* the stones are laid in courses, each course being uniform in thickness throughout its length but all courses need not be of the same thickness. See Fig. 39*a*.

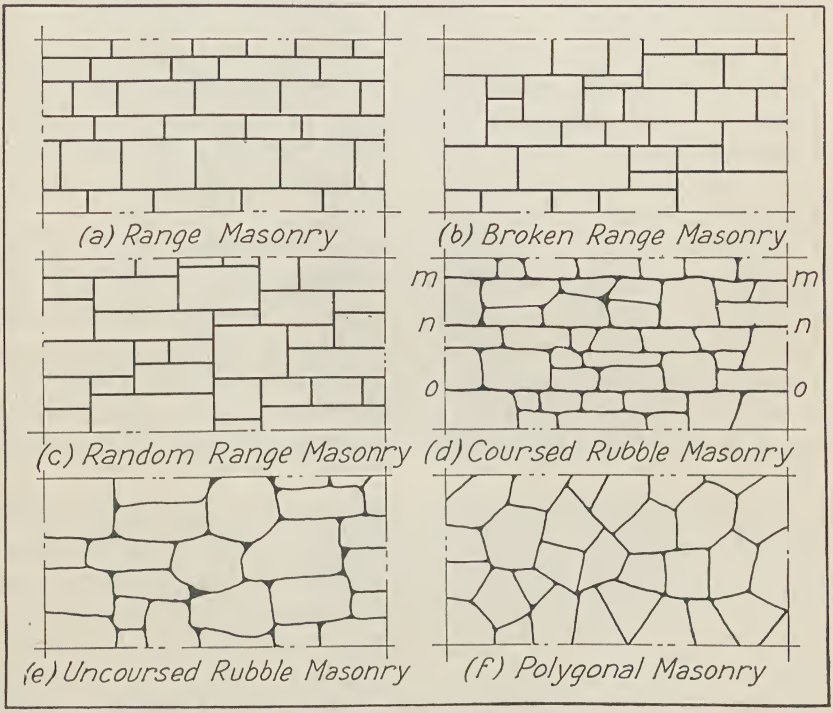


Fig. 39. Types of Masonry

In *broken range masonry* the stones are laid in courses but the courses are continuous for short distances only. See Fig. 39*b*.

In *random masonry* no attempt is made to form courses. See Fig. 39*c*.

The terms range, broken range, and random are usually applied only to ashlar and squared-stone masonry, but where rubble masonry is constructed of stratified stones the upper and lower surfaces may be parallel and random masonry result. In general, however, rubble masonry is divided into coursed and uncoursed rubble.

In *coursed rubble* the masonry is leveled at specified heights as shown in Fig. 39*d* or is laid in fairly regular courses marked *m–m*, *n–n*, *o–o* in the figure.

In *uncoursed rubble* the masonry is not leveled as in coursed rubble. See Fig. 39*e*.

In *polygonal masonry* the stones are irregular in shape without parallel edges and are shaped to fit the spaces they are to occupy, the joints being more or less uniform in thickness. See Fig. 39*f*. This type of masonry is sometimes called *cobweb rubble*.

**Backing.** — In rubble masonry the face and backing are usually of rubble, the better stones being picked out for the face, but concrete backing may be used.

The backing for squared-stone masonry and ashlar masonry may be rubble masonry, brick or hollow tile. Rubble masonry is not suitable for backing thin walls such as enclosure walls. If rough blocks are shipped to the building site and are there worked into shape the stone which would otherwise be wasted is used in the rubble backing. Ashlar or squared-stone masonry is not used for backing.

Concrete is also used for backing but it should not be placed against limestone or sandstone facing or against brick work in contact with such stone without providing a waterproof layer between the stone and the concrete. If such a layer is not provided the stone may be discolored and stained. Certain stones may not require such a coating but it should not be omitted without making a thorough investigation. Ashlar is often used as a veneer for concrete walls or other surfaces which are already in place.

The stones used in facing over brick or hollow tile backing should preferably be of such a height that they will work in with the backing, the horizontal joints of the face and backing coming at the same level at the intervals desired for bonding as described in the next section.

For illustrations of walls with stone facing and hollow tile backing see Article 20.

**Setting.** — The placing of stone in position in a structure is called *setting*. Stones are usually lifted with derricks, the stone being held with *grab hooks*, as shown in Fig. 40*a*, with *Lewises*, as shown in Fig. 40*b*, or with Pin Lewises inserted in inclined holes as shown in Fig. 40*c*. If Lewises are used Lewis holes must be provided. Some contractors use Lewises for all stones weighing over 75 or 100 lb. on account of the greater convenience and safety of this method, while others use *grab hooks* for stones as heavy as 400 lb. The most common type of Lewis is assembled in the hole as shown in 1, 2, 3, and 4 of Fig. 40*b*.

Stratified stone should be dressed in such a manner that it may be set

in the building with the natural quarry bed horizontal. This is important in stratified stone on account of the greater strength when placed in that direction and also on account of the greater resistance to weathering. When the quarry bed is placed vertical, water enters the stone more freely and weathering progresses more rapidly than when the quarry bed is horizontal. If the quarry bed is placed vertical and parallel to the face many stones scale off very badly.

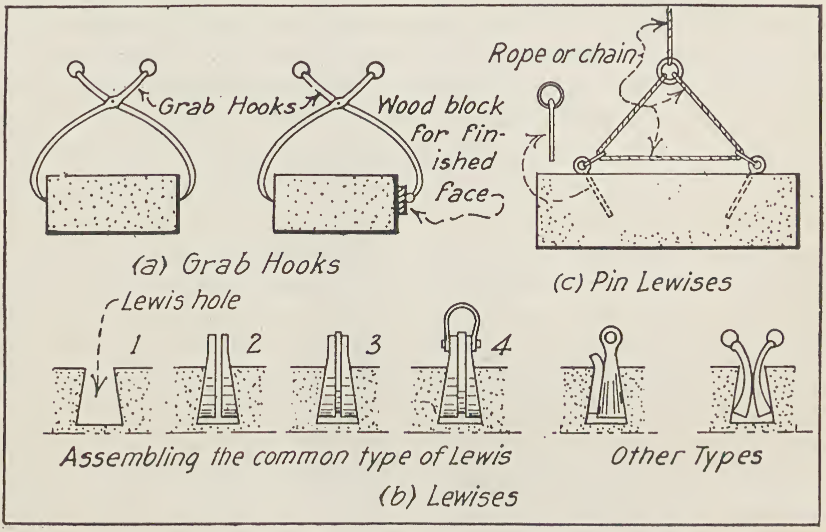


FIG. 40. Methods of Lifting Stone Blocks

The Indiana Limestone Company states that little attention need be paid to the setting of its product on its natural quarry bed. The great majority of such ashlar is sawed with the grain parallel to the face of the wall and monolithic columns are produced with the grain running vertical. However, most limestones are somewhat weaker, when loaded, parallel to the bedding than when the loading is perpendicular to the bedding.[1]

Door and window sills which have their ends built into the masonry should be bedded only at the ends, the space in between being left entirely free from mortar except for the pointing mortar which is applied later. If this practice is not followed the sills will be quite certain to break when the ends become loaded as the work progresses. This type of sill is called a *lug sill*. Very often window sills are made slightly shorter than the opening and are independent of the rest of the masonry, except, of course, the bed on which they rest. In this case the bed is completely

[1] Technologic Paper No. 349, Bureau of Standards.

filled with mortar. Such sills are called *slip sills*. Exterior steps are set with a slight pitch to the front so that they will drain. Stones projecting beyond the face of the wall should not be set until the mortar in the courses underneath has hardened and should be propped up until the wall above is built.

The following comments on setting are adapted from the Indiana Limestone Manual prepared by the Indiana Limestone Company.

In order to insure a uniform joint thickness it is common practice to place wood wedges at the front side of the mortar joint after the mortar has been placed. One wedge is placed near each end of each stone. As the stone is lowered on to the mortar bed it squeezes the soft mortar out until the stone finally rests on the wedges. After the mortar has set and before the joints are pointed the wedges are removed. To avoid their swelling in the wall and to make their removal possible, the wedges must be soaked just before they are used. As they dry out they shrink and become loose, the load then being carried by the mortar which has now had time to set. If the wedges are not thoroughly soaked before placing they will absorb water from the mortar and swell in the wall. This may result in lifting the stone, with the wall load it now carries, off of the mortar bed causing the spalling off of the edges of the stone where they bear on the wedges. It will also make the removal of the wedges impossible, in which case they must be broken off so as to clear the pointing mortar. The wedges should be made of soft pine or spruce and should be about $2\frac{1}{2}$ in. long, $\frac{7}{8}$ in. wide and taper from $\frac{1}{2}$ in. to $\frac{1}{8}$ in. Wedges may be necessary in setting stones with uneven beds or to prevent the crushing out of mortar when setting heavy stones. Ordinarily their use with stones having even beds is objectionable for they often result in improper bedding.

For setting large blocks of stone such as column sections, three lead pads or buttons are placed in each joint instead of using wedges. These pads are about 2 in. square and equal in thickness to the thickness of the joint. Mortar is placed in the joint around these pads, taking care to keep the mortar off of the tops of the pads. To insure the complete filling of the joints, mortar is worked into the joint with an old saw or a mortar sabre after the stone is placed.

Heavy column sections are sometimes set on sheet lead pads without mortar except for the pointing. The pad is made about $\frac{3}{4}$ in. smaller all around than the stone to allow for pointing. A hole is cut in the center of the pad to permit the lead to squeeze towards the center as well as outward as the pad deforms to an even bearing.

Thin ashlar facing should not be carried up more than two courses in advance of the backing and no bond stone or other stone having a wider

bed than the stone directly below it should be set until the backing has been built up level with the top of the lower stone.

Care must be used to insure that the wall loads of skeleton steel or concrete buildings are carried by the frame and not by the walls themselves. This may be accomplished by starting the work at two or three levels in the upper stories. It is desirable to leave the lower stories until the last to avoid their receiving excessive loads from the stories above as the structural frame deforms under the increasing dead load.

A waterproof membrane of tar paper and a bituminous cement or of slate should be provided on top of the foundation wall and under the base course to keep moisture from being carried into the lower courses of the masonry by capillary attraction and causing efflorescence, stain, and disintegration. When using any so-called soft stone possessing comparatively high absorption for any work in contact with grade, it is desirable that the base course be coated with a colorless waterproofing.

In general, stone setting should not be done when the temperature is below 20 deg. or below 25 deg. when the temperature is falling. During cold weather the mortar sand should be dried out and heated and the water should be heated. The mortar should be used while it is warm. If any ice or frost is on a stone it should be steamed off before setting. Salt should not be used to remove ice from Lewis holes or anchor holes or for any other purpose as it will cause efflorescence. Stone covered with ice should be taken into a warm place and be allowed to thaw and dry.

**Bond Stones, Anchors.** — In stone masonry, longitudinal bond is secured by breaking joints as in brick masonry although in broken range and random masonry a vertical joint may sometimes be three stones in height.

Bond between the face and backing may be secured by headers or bond stones as in brick masonry, by bond courses, by metal anchors, or by bond courses or stones and metal anchors used together.

The bond or anchorage required between the face and backing depends upon whether the wall is a bearing wall or a nonbearing wall and upon whether the facing is to be considered in the required thickness of the wall.

*Headers* extending entirely through the wall, as shown in Fig. 41*a*, provide an effective method of bonding and are suitable for use in bearing walls.

*Bond stones* arranged in courses projecting into the backing an amount equal to the thickness of the other facing stones as shown in Fig. 41*b* and with one bed of every stone in contact with a bond stone will tie the face stone to the backing securely enough for nonbearing walls where the facing is not considered as a part of the required thickness of the wall.

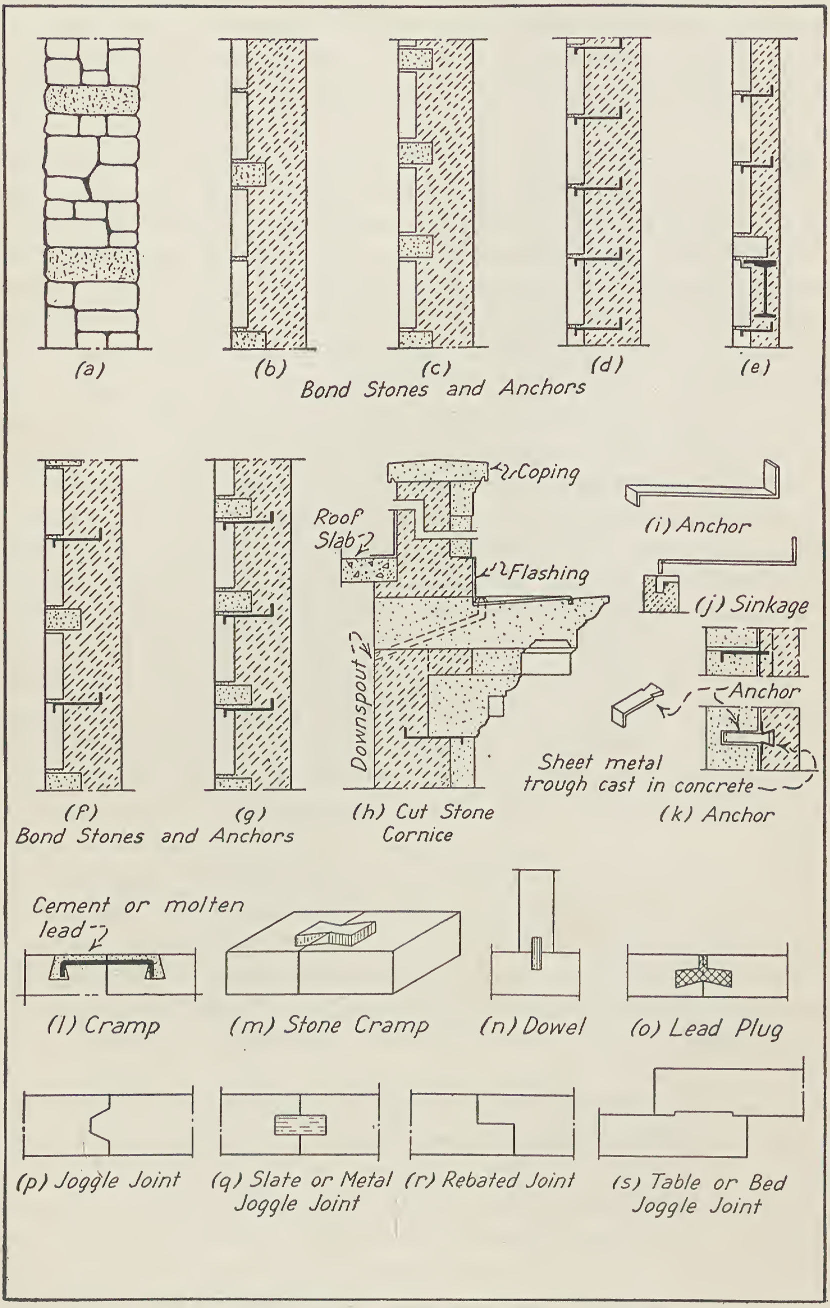


FIG. 41. Bonding and Anchoring Stone Masonry

The arrangement shown in Fig. 41*c* makes every other course a bond course. This provides a more secure bonding between the facing and the backing but is not usually considered suitable for bearing walls if the facing is required to carry its share of the load. All of the stones in a bond course are not usually bond stones and in broken range and random masonry the bond stones are distributed at random throughout the wall with each stone providing the tie for a given surface area. See p. 168.

*Metal anchors* are extensively used to tie the facing to the backing as shown in Fig. 41*d*. When this method of anchoring is used on bearing walls, the facing cannot be considered as carrying any part of the load and it cannot be included in the required thickness for any type of wall.

Bond courses and anchors are commonly used together. In Fig. 41*e* the anchors are supplemented by a bond course bearing on the spandrel beam of each story. This type of construction is desirable for panel and inclosure walls in skeleton construction. Such walls are commonly 12 in. thick and may require that anchors extend entirely through the backing for adequate bond, the upturned end being against the inner face.

The combination of bond courses and anchors shown in Fig. 41*f* is quite effective but if the facing of bearing walls is to be considered as carrying its share of the load and is to be considered in the required thickness every alternate course should contain bond stones and every stone not a bond stone should be anchored to the backing as shown in Fig. 41*g*. The bond stones should occupy at least 20 per cent of the wall surface. If stones are not in courses the equivalent bonding should be provided. See p. 168.

The method of anchoring a cut stone cornice is illustrated in Fig. 41*h*.[1] Special anchors should be provided for cornice and belt course stones that do not have sufficient bearing to balance on the wall. These anchors should be hooked into the stone at least 2 in. and should be spaced about 2 ft. apart, with at least two anchors to a stone.

Further discussion of the bond required between the facing and backing is given in the paragraph on "Faced Walls and Veneered Walls."

**Construction and Placing of Anchors.** — Anchors are usually placed in the horizontal joints and hooked into the tops of the stones but at times it is desirable to place anchors in the vertical joints near the top and near the bottom of the stone and hooking into the side, especially when hollow tile backing is used. A typical form of anchor is shown in Fig. 41*i*.

Anchors should not be placed in the mortar joint but a *sinkage* or depression of ample width and of a depth slightly greater than the thickness of the anchor should be provided at the back of anchor holes as shown in Fig. 41*j*. There are two reasons for providing sinkages. With

[1] From pamphlet issued by The Ohio Quarries Company.

the $\frac{1}{4}$-in. joints usually used in ashlar masonry there would be difficulty in placing the anchors in the joints and the stones would tend to rest on the anchors rather than to secure uniform bearing on the mortar joint. This condition would tend to cause the stones to crack. The sinkages do not fit the anchor accurately but are usually larger than necessary and are crudely formed. Anchor holes should be kept about 2 in. from the outer surface of the stonework in order that the anchor may be adequately protected.

Anchors should be made of wrought iron or soft steel galvanized after cutting and shaping. Galvanizing is required to prevent rusting, which may stain the stonework, split the stone by expansion while rusting, or finally destroy the anchor. The coating of anchors with paint will not take the place of galvanizing but may be done as an additional precaution. Other protective coatings are described in Article 21.

For ashlar and other ordinary facing stone the Indiana Limestone Company recommends anchors $\frac{3}{16}$ in. thick by 1 in. wide having one end bent down a scant inch into the stone and the other end bent up a full 2 in. into the backing and of a length that will extend from the anchor hole a distance of about $8\frac{1}{2}$ in. into the brick work where brick is used for backing or to hook over the center web of hollow tile where tile is used for backing. For very high courses or heavy work, anchors $\frac{1}{4}$ in. thick by $1\frac{1}{4}$ in. wide may be used or even $\frac{3}{8}$ in. by 2 in. for special purposes, but such heavy anchors are seldom necessary.

The anchors recommended by the National Building Granite Association are $\frac{1}{4}$ in. by $1\frac{1}{4}$ in. turned down into the granite about $1\frac{1}{4}$ in. and extending into the backing 8 in. if the thickness of the wall permits, the end being turned up $1\frac{1}{2}$ in. into the backing.

For anchoring stone facing to concrete columns or steel columns fireproofed with concrete, $\frac{3}{8}$-in. round or square galvanized steel rods may be used. These should be hooked down 2 in. into a hole drilled into the stone at one side and may be bent around the column and be hooked in a similar manner at the other side, or may be hooked into a hole drilled into the concrete on the side of the column, an anchor being used on each side. These anchors are bent and cut to size on the job.

A patented form of anchor which is very convenient for use in anchoring a stone facing to a concrete wall is shown in Fig. 41*k*. Before the wall is poured sheet metal troughs are tacked to the side of the form for the outer face. These are placed vertically and at the proper intervals. When the forms are removed the trough is exposed in the face of the wall. It is beveled on the sides to receive an anchor with a dovetailed end as shown in the figure. The anchors may be moved up and down to fit into the joints. This type of anchor is more convenient and much more

effective than most types of anchors which are cast in concrete walls and are bent out into the mortar joints of the facing.

**Lewis Anchors, Cramps, Dowels, etc.** — Forms of anchors, other than those just described, are sometimes required. When it is necessary to suspend the soffits of openings from steelwork above, Lewis anchors similar to the ordinary Lewis, are used. The Lewis holes for the anchors should be from 3 or 4 in. deep.

*Clamps* or *cramps* are used to keep coping stones, stair rails, etc., from pulling apart. They are made of flat iron varying from $1\frac{1}{4}$ by $\frac{1}{4}$ in. for light work to $1\frac{1}{2}$ by $\frac{1}{2}$ in. for heavier pieces. These are turned down $1\frac{1}{2}$ or 2 in. at the ends and vary in length from 6 to 12 in. They may be set in sinkages in the tops of the stones or they may be set under the stones with their ends turned upward into the stones. *Cramps* should be heavily galvanized after being bent to shape. On high-class work they may be protected by pouring molten lead around them as shown in Fig. 41*l*, the holes being larger at the bottom than at the top to hold the lead and anchor in place. Cramps or keys made of slate or other stone or of metal may occasionally be used in place of cramps as shown in Fig. 41*m*. The lead plug shown in Fig. 41*o* serves the same purpose but is rarely used. In forming the lead plug, molten lead is poured in the vertical channel and fills the dove-tailed holes sloped so that the lead can easily fill the holes. Brass or bronze dowels made of solid rods or of pipe are commonly used to hold the ends of balusters, window mullions and similar pieces in position as shown in Fig. 41*n*. The ends of inclined copings may be doweled into the kneelers as shown in Fig. 24*e*.

**Joggled, Tabled and Rebated Joints.** — Two types of joints which are rarely used are the *joggled joint* shown in Fig. 41*p* and the *table joint* or *bed joggle joint* shown in Fig. 41*s*, designed to prevent movement along a joint. These joints are very expensive to form. A slate or metal joggle joint, as shown in Fig. 41*q*, may be formed more cheaply. The joint is not usually continuous. A rebated joint is shown in Fig. 41*r*. This type of joint is sometimes used for coping stones placed on a slope.

**Faced and Veneered Walls.** — Stone walls may be classed as faced walls and veneered walls according to the provision which is made for bonding the face to the backing. If the facing and backing are securely bonded together so that they will act as a unit the entire thickness of the wall may be considered in strength calculations and in satisfying the requirements for minimum thickness. Such walls are called *faced walls.* If the facing is not attached and bonded to the backing to such an extent as to form an integral part of the wall, the wall is called a *veneered wall* and only the backing may be considered in strength calculation and in satisfying the requirements for minimum thickness.

Building codes differ very greatly in their requirements for bond and anchorage. The following requirements are taken from the Report of the Building Code Committee of the Department of Commerce entitled Recommended Minimum Requirements for Masonry Wall Construction.

*Requirements for Faced Walls.* — Materials used for facing shall be not less than $3\frac{3}{4}$ in. thick, and in no case less in thickness than one-eighth the height of the unit, excepting that spandrel and other recessed panels, when approved, may be higher than eight times their thickness, provided they are of the minimum thickness required.

The maximum allowable compressive stresses on faced walls due to combined live and dead loads shall not exceed those elsewhere prescribed for masonry of the type which forms the backing. Where properly bonded to the backing the full cross-section of the facing may be considered in computing bearing strength.

Faced walls shall be not less in thickness than is required for masonry walls of the type which forms the backing. Where properly bonded to the backing the facing may be considered a part of the wall thickness.

Stone ashlar facing shall have at least 20 per cent of the superficial area not less than $3\frac{3}{4}$ in. thicker than the remainder of the facing to form bond stones, which shall be uniformly distributed throughout the wall.

When bond stones in every alternate course are at least $7\frac{1}{2}$ in. thick, bonded into the backing at least $3\frac{3}{4}$ in., and at least 20 per cent of the superficial area of the wall is constituted of such bond stones uniformly distributed, the ashlar facing may be counted as part of the wall thickness. Every stone not a bond stone and every projecting stone shall be securely anchored to the backing with substantial noncorrodible metal anchors.

Anchors for attachment of facing or veneering to the backing should be not less than three-sixteenths by one inch in cross-section, and should either be bent or of sufficient length to develop their full strength in bond. Such anchors should be thoroughly protected from moisture, or should be of noncorrodible metal.

A faced wall is illustrated in Fig. 41*g*.

A very severe requirement for faced bearing walls is that of the Building Ordinances of Chicago which is as follows:

(*a*) Ashlar facing of masonry walls shall only be considered as a part of the wall for the purpose of carrying weight, when it has a minimum bond as follows:

(*b*) Every second course to be a bond course; this bond course to extend into the backing a distance equal to the thickness of the ashlar. In addition to such bond, each stone in all courses shall be tied to backing by two galvanized iron anchors. No ashlar shall be less than 4 in. thick, nor shall the height of any stone exceed five times its thickness.

*Requirements for Veneered Walls.* — Stone or architectural terra cotta ashlar, or other approved masonry material used for veneering, shall be not less than 3

in. thick. In stone ashlar each stone shall have a reasonably uniform thickness, but all stones need not necessarily be the same thickness.

The maximum allowable compressive stresses on the backing of veneered walls, due to combined live and dead loads, shall not exceed those prescribed for masonry of the type which forms such backing. In no case shall the veneering be considered a part of the wall in computing the strength of bearing walls, nor shall it be considered a part of the required thickness of the wall.

When walls are veneered with brick, terra cotta, stone or concrete trim stone the veneering shall be tied into the backing either by a header for every 300 sq. in. of wall surface, or by substantial noncorrodible metal wall ties spaced not farther apart than one foot vertically and two feet horizontally. Headers shall project at least $3\frac{3}{4}$ in. into the backing, and anchors shall be of substantial pattern. When veneering is used special care shall be taken to fill all joints flush with mortar around wall openings.

Veneered walls shall not exceed 40 ft. in neignt above foundations.

Veneered walls are illustrated in Fig. 41*b* to *e*.

The panel walls of skeleton construction buildings are carried on the structural frame and are usually veneered walls with hollow tile or brick backing. Such walls should have one bond course placed directly on the spandrel beams. One bond course to a story may be sufficient but sometimes it is advisable to use two or the equivalent. Many building codes do not require any bond courses for panel walls, but this is poor practice. A panel wall resting on a steel spandrel beam is shown in Fig. 41*e*.

**Joints and Pointing.** — The mortar layers between stones are called *joints*. Horizontal joints are *bed joints* or simply *beds* and vertical joints are known as *joints* or *builds*.

In rubble masonry the joints are neither uniform in thickness nor constant in direction but they simply fill the spaces between stones of irregular shape. Large spaces in the backing may have small pieces of stone called *spalls* embedded in the mortar.

In squared-stone masonry the joints are horizontal and vertical and are more or less uniform in thickness the stones having been roughly dressed to shape. In general the joints in squared-stone masonry will be from $\frac{1}{2}$ in. to 1 in. in thickness.

In ashlar or cut stone masonry the stones are accurately dressed to shape so that the joints do not exceed $\frac{1}{2}$ in. in thickness. A very common thickness of joint for the ashlar facing of buildings is $\frac{1}{4}$ in. Joints $\frac{1}{8}$ in. in thickness are sometimes used for interior stonework but are not desirable for exterior work.

The mortar in the horizontal and vertical joints of ashlar masonry is kept back from the face in setting the stone or is raked out to a depth of about $\frac{3}{4}$ in. In this space a special mortar is placed to make a tighter and more attractive joint. This process is known as *pointing*. The various

types of joints formed by pointing are shown in Fig. 42. Pointing is done after the mortar in the joint has set and usually after all of the stone has been placed and the wall has received its full load.

Squared-stone masonry may be pointed in the same manner as ashlar or the joint may be finished at the time the stone is set.

The joints in rubble masonry are usually finished when the stones are set and no pointing is done.

Often the joints of squared-stone masonry or rubble are made flush with the surface of the stones and after the mortar has set a narrow bead of colored mortar is run on the wide joints to give the effect of narrow joints. See Fig. 42*b*. The wide joint is frequently made the same color as the stone and the narrow joint a contrasting color.

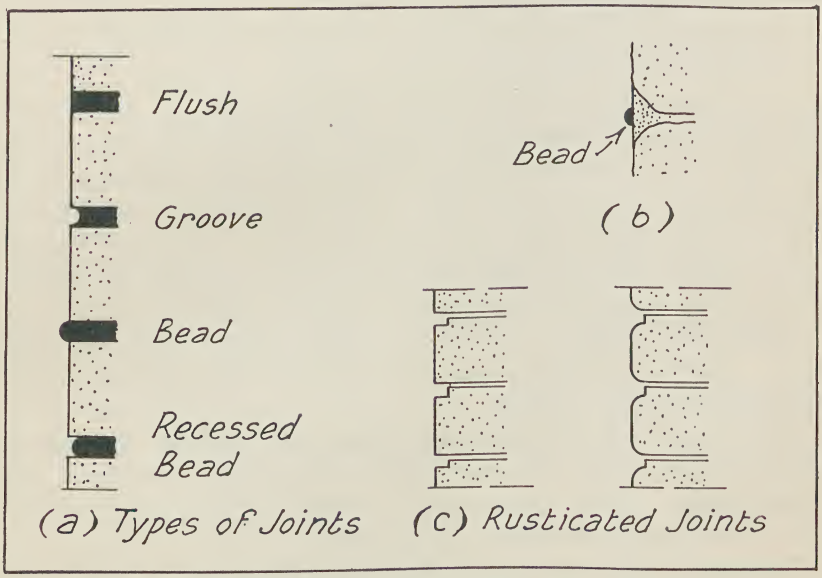


Fig. 42. Types of Joints for Stone Masonry

The joints are often emphasized by shaping the stones as shown in Fig. 42*c* to form *rusticated* or *rebated* joints. This type of joint is frequently used in the stonework on the lower stories of buildings to give a massive appearance.

The following discussion concerning the vertical joints of cornices, copings, etc. is quoted from the Indiana Limestone Manual.

It is very important that the vertical joints in all cornices or belt courses projecting from the face of building wall, the top members of all main cornices and copings and balustrade rails be thoroughly filled with setting mortar. Where this is not done the passage of water is sure to show in some manner on the face of stone and probably disfigure an otherwise fine piece of work.

Vertical joints in such members cannot be properly filled simply by slushing up at time of setting, and should always be grouted solid. It is a mistake to make these joints less than a full $\frac{1}{4}$ in., regardless of the thickness of joints elsewhere throughout the work. The stone should be set with the vertical joints dry, and the exterior profile of the members be carefully calked with picked oakum or newspapers soaked in water, and the joint be poured full with as thick a mortar grout as can be properly worked into same, allowing the usual $\frac{3}{4}$ in. of depth at top of joint for pointing up later. With very large stone, it is advisable to cut an inverted V-shape key channel on vertical joints to facilitate this grouting.

The calking is later removed, and thus provides the necessary space for pointing up of joints. If the grout is too thin, it will tend to shrink away from the stone in setting and the joint may not be tight. To void this shrinkage, a proper proportion of sand should always be used and the grout be continually stirred until used to prevent the separation and settling of the sand.

Large cornice members are sometimes calked with lead wool as an extra precaution. Where this is to be done, the grouting should only fill the joint to within about 2 in. of the top, and a full inch of this depth be calked with lead wool, driven in tightly, leaving the upper $\frac{3}{4}$ in. for pointing mortar.

Sometimes the grouting is dispensed with, the stone being bedded with vertical joints buttered with mortar, and calking with lead wool or oakum relied upon to make them tight, but this is not considered as good practice as the proper grouting of these joints. Lead wool, when used, should supplement and not replace the thorough filling of vertical joints in cornices and other exposed horizontal members.

Still another scheme is to substitute an elastic calking cement for the $\frac{3}{4}$ in. of pointing mortar on all top surfaces, washes, gutters, etc. Only calking compounds that are light in color and free from oils and grease that would discolor the stone are suitable for this purpose.

The greatest advantage of an elastic calking compound is for calking the coping and parapet walls built on top of modern steel frame structures, rather than for work in connection with buildings having solid masonry walls, as these skeleton frame structures are more subject to movement from wind stress and from expansion and contraction of the structural frame.

For certain types of step and platform work, in connection with approaches and other outside work, the filling of vertical joints with mortar is not desirable, as slight movements in the supporting masonry will often be caused, not only by frost action but by seasonal moisture conditions in the surrounding soil. For such work a lead joint is then desirable. This may be specified, as follows:

The joints in all steps and platform slabs shall be calked on the underside with oakum or rope yarn and then be filled with molten lead, well pounded in and completely filling the joint so as to finish smooth with the surface of the stone.

**Mortar.** — Stone masonry should usually be set in cement mortar consisting of 1 part portland cement to 3 parts sand. If lime is used to increase the workability of the mortar, not more than 15 per cent of the volume of the cement should be replaced by an equal volume of lime.

Ordinary portland cement mortar will stain limestone and some other stones, so for setting facings of such stones non-staining white portland cement mortar or lime mortar may be used. In any case the possibility of mortar staining face stone should be investigated before selecting the mortar.

A lime mortar which will not stain light-colored stones consists of 1 part hydrated lime or properly slaked and prepared lump lime paste, to not over 3 parts of washed sand, with the addition of non-staining cement in an amount equal to 15 per cent by volume of the lime used, the cement to be added and thoroughly worked into the mixture in small batches just prior to use. The sand must be clean and both sand and water must be free from all elements that would tend to cause staining of the stone.

The addition of the white portland cement to lime mortar is necessary to hasten the setting. In some cases a lime-cement mortar may be used. This mortar should consist of 1 part lime, 1 part non-staining cement, and 6 parts of washed sand.

Many building codes require portland cement mortar for ashlar facing as well as the backing of inclosure and other outside walls.

A mortar made of white non-staining waterproof cement or of an ordinary white non-staining cement with suitable integral waterproofing, used as a parging on the back of stone, is one of the best means of preventing staining from ordinary cement mortar used in laying up the backing.

Foundation walls should always be laid with portland cement mortar.

The mortar for pointing should not be too rich or it may shrink away from the stone, become loose, and eventually fall out of the joints. A mortar consisting of 1 part portland cement (non-staining if required), 2½ parts of fine sand and about 15 per cent of lime to make the mortar more workable gives good results for pointing.

**Damp-proof Coatings and Backpainting.** — Face stone is commonly protected from stain due to the mortar in the joints and in the backing by damp-proofing in some form. This is particularly necessary in the case of limestone.

The National Building Granite Quarries Association recommends that at least 12 hours before the granite is set, all surfaces not exposed be thoroughly coated with an approved damp-proof compound to within 1 in. of the exposed face, and that after the granite is set, and before backing up, another coat of the same damp-proofing be applied to the back for the special purpose of covering the backs of the mortar joints. The painting of the granite may be omitted when it is definitely known that the setting mortar will not stain the granite but the backs of the joints should be damp-proofed in any event to guard against seepage,

through the joints, of moisture from the mortar or material used in backing the granite work which will cause discoloration around the face joints or on surface of the granite.

The use of damp-proof coatings is not approved by the Indiana Limestone Company for its product. This company recommends that mortar used in the face and backing be such that it will not stain the face stone, the necessity for damp-proofing thus being avoided. The plastering of the entire backs of all stone, while wet, with a $\frac{1}{2}$-in. coat of setting mortar before backing up, is also recommended. When a stone facing is placed against concrete the concrete and not the stone should be painted with a damp-proof compound. Where concrete must be poured behind face stone this company recommends that brick or tile be placed against the stone, that the back of this material be damp-proofed, and that the concrete be poured against the damp-proof backing.

If limestone or other stone which will stain is used as a trim for brick faced walls with the brick facing and other brickwork in contact with the stone, the only way of damp-proofing is to back paint the stone and in addition all sides of the stone that are built into the walls should be parged with lime or non-staining cement mortar. These precautions are not necessary if lime mortar or non-staining cement mortar is used for the brickwork.

The top of concrete foundation walls just under the first course of stone should be waterproofed in some manner to prevent moisture in the foundation walls from being drawn up into the stonework and causing staining due to elements contained in the soil. The same results may be less effectively accomplished by placing a layer of asphalt saturated felt, slate, or sheet lead between the top of the wall and the stonework. Sheet lead will equalize the pressure of the stone on the foundation wall better than felt but is much more expensive. In all cases the top of concrete foundation walls should be given a heavy coat of hot asphalt or damp-proof paint.

**Efflorescence.** — For a discussion of efflorescence see Article 18.

**Colorless Waterproofing Materials.** — Colorless waterproofing materials may be used on the surface of stone masonry to keep moisture from penetrating the walls and causing dampness, efflorescence, and disintegration due to frost action and efflorescence. The results of a study of colorless waterproofing compounds by D. W. Kessler are given in Technologic Paper No. 248 of the Bureau of Standards. The conclusions reached are as follows:

1. The most effective waterproofing materials in this series are those the waterproofing elements of which are heavy petroleum distillates, fatty oils, or insoluble soaps.

2. The effectiveness of any waterproofing may be greatly influenced by the character of the pores in the stone.

3. Stones having close textures are more difficult to waterproof than those with large pores.

4. The treatments giving the highest waterproofing values and appearing to be most durable are those which use paraffin as the waterproofing element, either alone or in conjunction with other materials. The deterioration or loss of waterproofing value of materials of this type is not appreciable within a period of two years.

5. Waterproofing materials employing resinous substances as the waterproofing element are not durable.

6. Materials consisting of aqueous solutions, the purpose of which is to react chemically with the stone or to act merely as water repellants, have only temporary effects.

7. Separate aqueous solutions which react chemically with each other and form insoluble substances in the pores of the stone give low waterproofing values and deteriorate rapidly.

8. In general, those materials which gave the highest waterproofing values produced the greatest discolorations. The amount of this discoloration was proportional to the porosity of the stones. These discolorations decrease on exposure to the weather and after a year or more, depending upon their intensity, they are compensated for by the fact that the treatments tend to prevent the accumulation of dust and soot on the surface of the stone.

**Trim Stone.** — Cut stone is frequently used as a trim around window and door openings and for belt courses, copings, and cornices in walls constructed of brick or rubble masonry. Stone used in this manner is called *trim stone.*

**Cast Stone.** — The use of cast concrete units, commonly known as *cast stone,* to replace cut stone has been growing in recent years. Cast stone consists of molded blocks of concrete with special surface treatment. They may be formed in any of the shapes obtained by cutting the natural stone and may have surface finishes which resemble the rubbed finish commonly used on limestone and other stones, or any of the tooled finishes. Special aggregates may be used next to the face or for the entire block so that when the cement surface film is removed by etching with acid or tooling the face will resemble granite, marble, and other natural stones, or the aggregate may be chosen simply to produce an attractive finish without attempting to imitate any natural stone.

The molds used may be constructed of sand, as in iron founding, or of plaster, glue, concrete, wood, or steel. Sand molds are only satisfactory for use when one piece of a given shape is required. Plaster molds are made from a clay or plaster model of the piece to be made. In making plaster molds, the model is coated with shellac and then greased or oiled.

Plaster of paris is then poured over the model and in setting forms a mold which follows exactly the form of the model. The mold is cut as necessary to remove it from the model and after drying, shellacing, and greasing is ready for use. Several castings may be made from a single mold.

Glue molds are made by shellacing the model; covering it with a layer of clay; forming a plaster cast over the clay; removing the plaster cast with its clay lining from the model by cutting where necessary; removing the clay from the cast and cleaning the cast; replacing the plaster cast around the model; pouring hot liquid glue in the space formerly occupied by the clay and allowing the glue to harden; removing the plaster from the glue mold thus formed; and cutting the glue mold where necessary to remove it from the model. The glue model is then painted on the inside and after greasing is ready for use. Having the model and the plaster cast on hand, additional glue molds can be cheaply made. Glue molds become too soft for further use after three or four castings have been made. They are used on intricate castings with under cuts from which they can be removed on account of their elasticity.

Concrete molds are made in the same manner as plaster molds. They can be used a larger number of times.

Plain blocks such as ashlar, sills, and belt courses can be made in wood molds which may be used many times before discarding.

Steel molds are too expensive to make except for pieces which are duplicated many times. For this reason steel molds are not used for making cast stone where extensive duplications are not common but they are used for making concrete brick, blocks, and tile.

The three processes used for making concrete blocks and tile as described in Article 20 are also used in making cast stone. These processes are the dry-tamp process in which a mixture of dry consistency is tamped into molds by tampers operated by hand or machine, the molds being removed immediately after tamping; the pressure process in which pressure is applied instead of tamping; and the wet-cast or pour method which uses a concrete of a consistency that can be poured into the molds and which requires that the molds be left on until the concrete has become hard enough to stand handling. The wet-cast process is probably the most common.

Cast stone is cured by the same methods as used for concrete blocks described in Article 20.

For further discussion of surface finishes see Articles 20 and 22.

One of the problems in connection with the manufacture of cast stone is the prevention of *crazing*. Crazing consists of small cracks of web-like nature which often form on the surface of cast stone. Circular No. 304 of the Bureau of Standards states that:

It is the result of volume changes incident to variations in moisture and temperature and the setting of concrete. With very thin rich coatings on relatively lean bodies crazing generally appears. How to prevent crazing on concrete products is a question which is now engaging the attention of many investigators. However, much can be done by the concrete products manufacturer to lessen the tendency to craze by using lean facing mixtures, providing thorough curing, avoiding excessive troweling of surfaces, not using too much water, using coarse surfacing materials, and removing the surface film of cement in which the cracks are often so pronounced. In some cases the use of a different body mix might be helpful. Exposure of fresh concrete to the sun or wind should be avoided.

**Stone Arches.** — Stone arches are extensively used in building construction to span openings in walls and for arcades. The parts of an arch and the various types of arches have been discussed in Article 17. The stones forming the arch ring are accurately cut to shape preferably

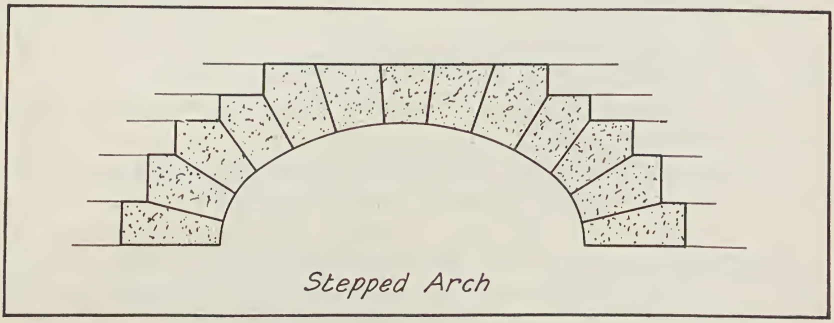


FIG. 43. The Stepped Arch

with their bedding plans perpendicular to the arch axis. They are set in cement mortar. The backs of stone arches are commonly stepped, as shown in Fig. 43, to facilitate the joining of the arch stones and the stone courses of the wall.

## Minimum Wall Thickness

The factors which affect the thickness of masonry walls are discussed in Article 17.

The recommendations of the Building Code Committee of the Department of Commerce for stone walls are as follows:

**Lateral Support and Thickness.** — Rubble stone walls shall be 4 in. thicker than is required for solid brick walls of the same respective heights, but in no part less than 16 in.

The minimum thickness for walls or piers of ashlar masonry properly bonded shall be the same as required for solid brick walls and piers under

similar conditions. See Article 18. (Ashlar masonry is defined by the Building Code Committee as "Masonry of sawed, dressed, tooled, or quarry-faced stone with proper bond." It would include squared-stone masonry.)

The lateral support for stone walls shall conform to the same requirements specified for solid brick walls. See Article 18.

**Bond.** — Bond stones extending through the wall and uniformly distributed shall be provided to the extent of not less than 10 per cent of the area, and there shall be at least one bond stone for every eight stretchers. See the paragraph on "Veneered and Faced Walls" in this article.

**Chases and Recesses.** — Chases and recesses in stone walls shall not exceed in extent those permitted for solid brick walls under the same conditions. See Article 18.

**Veneered and Faced Walls.** — See the paragraph on "Veneered and Faced Walls" in this article.

### REFERENCES

Recommended Minimum Requirements for Masonry Wall Construction by the Building Code Committee of the Department of Commerce.

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## ARTICLE 20. HOLLOW TILE AND CONCRETE BLOCK MASONRY

**Uses.** — Hollow clay tile (sometimes called structural tile) and hollow concrete blocks and tile are used for exterior bearing and curtain walls and for bearing and nonbearing partitions. They are also used for backing up exterior walls faced with brick or stone. Foundation walls for hollow tile and concrete block walls may be of these materials or of concrete, brick, or stone. Gypsum tile or blocks are used only for interior nonbearing partitions.

**Manufacture, Grades and Properties.** — Hollow clay tile are made by forcing plastic clay through specially formed dies and baking the resultant shapes until they are hard and durable. They are made in three grades:

dense, semi-porous, and porous. *Dense tile* are made from clay as described above. *Semi-porous tile* are made by mixing pulverized coal with the plastic clay. This coal burns out while the tile are being burned, leaving tiny cells throughout the tile. *Porous tile* are made by mixing sawdust with the plastic clay. The sawdust burns out in the kilns leaving larger cells than those left by the pulverized coal and the result is a more porous tile. Dense tile are heavier, stronger, and more durable than the other grades and are used in exterior walls and bearing partitions as well as nonbearing partitions. Semi-porous and porous tile are less brittle than dense tile but they will resist the action of fire better and they are better non-conductors of heat than dense tile. They may be cut with a saw and will hold nails and screws. Semi-porous and porous tile are used for nonbearing partitions.

Concrete building units[1] may be divided into three classes: brick, blocks and tile. Concrete brick have been considered under "Brick Masonry" and will not be included here. The blocks are larger and are relatively heavier than the tile. Concrete building units are made from a mixture of portland cement, fine aggregate, coarse aggregate and water. The fine aggregate is usually sand. The coarse aggregate may be gravel, crushed stone, crushed slag, cinders, and a patented clay product called Haydite which is given a cellular structure by a special process. Cinders and Haydite are used to make light-weight blocks and tile.

Three processes are used in the manufacture of concrete building units: the dry-tamp process and the pressure process, which may be classed as dry or semi-dry processes, and the pour process which may be classed as a wet process.

In the *dry-tamp* and *pressure processes*, the concrete which is used is of such dry consistency that the blocks may be removed from the molds immediately after compacting. In the dry-tamp process, the compacting is done by means of tampers operated by hand or machine whereas in the pressure process the compacting is done by pressure created by hydraulic means or by power or hand through a system of levers and toggle joints.

In the *pour process* a wet mix is poured into the molds and subjected to tamping, vibrating, or jigging to make certain that the molds are completely filled. The concrete must remain in the molds until it has set to such a degree that the blocks will retain their shape when the mold is removed and will stand handling.

Molds used for all of the processes may be divided into three classes. In some of the molds the units are cast with the face up, in others the

[1] Circular of Bureau of Standards, No. 304. Properties and Manufacture of Concrete Building Units. Recommended Practice for the Manufacture of Concrete Building Units. *Proceedings* of American Concrete Institute, 1925, p. 473.

face is down, and in others it is at the side of the mold. The face-up mold permits any surface treatment to be easily made. The face-down mold is probably the most used type for producing special faced units. In this type, a special facing material may be placed in the bottom of the mold before placing the material for the body of the unit. Units with faces of special design, such as rock face, are made in molds of this type. Tiles without special surface treatment are commonly made in molds with the face at the side.

After leaving the molds the units should be cured. This involves the providing of moisture and heat. The best results are secured by steam curing. Other methods of curing are by storing in moist chambers and by sprinkling.

*Gypsum tile* or *blocks* are made by placing a mixture of calcined gypsum and a small amount of fiber with water and pouring into a mold to secure the desired shape. Setting takes place very rapidly so that the molds can be removed in a few minutes. Only one grade is manufactured. Gypsum tile are good non-conductors of heat and quite fire resistant. Their strength is sufficient for nonbearing partitions. Gypsum is not satisfactory material to use in the presence of moisture. These tile are easily cut with a saw.

Gypsum blocks are not used in exterior walls. The surfaces are usually plastered but partitions in warehouses and similar structures are often left unplastered. Gypsum plaster only should be used on gypsum blocks. Other plasters will not adhere to gypsum.

**Mortar Joints.** — The joints of hollow tile and concrete block walls and partitions should be made with portland cement mortar composed of 1 part cement and not over 3 parts sand. Hydrated lime, not to exceed 15 per cent of the volume of the cement, may be used to make the mortar work easier.

When the surface of hollow tile is exposed a $\frac{3}{8}$-in. flush, struck or weather joint as described under brick masonry may be used. The same joints may be used for concrete blocks or a raked joint may be used.

The joints in gypsum-block partitions should be made of gypsum mortar consisting of 1 part of unfibered gypsum plaster to 3 parts of sand.

**Hollow Clay Tile Shapes.** — Hollow clay tile are manufactured in a great variety of shapes. The standard shapes are manufactured in plants located in all parts of the country but the special shapes are patented and the plants manufacturing them are not so widely distributed. On account of freight charges hollow tile are not shipped great distances.

Besides the regular tile used in the body of the wall it is necessary to

have jamb tile, sills, corner tile, etc., for use with each of the special shapes. In all cases the parts of the tile forming the inner and outer surfaces are called the *shells* and the cross members are called the *webs*. The open spaces are called the *cells*. The thickness of webs varies from $\frac{1}{2}$ to $\frac{3}{4}$ in. and of shells from $\frac{3}{4}$ to 1 in.

In *end construction*, hollow tile are placed with the cells vertical while in *side construction* the cells are horizontal. Specifications and building codes commonly require that bearing walls be of end construction because tiles will carry a greater load with the cells placed vertically than they will with the cells placed horizontally; however, tests[1] show that end construction walls are stronger than side construction walls only when built with rich mortar and with the central longitudinal webs of the tiles in bearing on the webs of the tiles above and below, which condition does not usually exist.

Nearly all of the patented forms of hollow tile are for side construction to gain the advantages of that type. The disadvantage of the lower strength of side construction is overcome to a large extent by devising a shape which will place the vertical shells of each tile directly over the vertical shells of the tile below, or, in other words, the vertical shells are aligned. In this way the load is transferred directly from the vertical shells of each tile to the corresponding vertical shells of the tile below.

Many patented shapes are so constructed that there is not a continuous joint through the wall and thus furring is not required by the transmission of moisture. In the standard forms this horizontal joint is continuous in side construction; in end construction the vertical joints may be continuous unless buttered joints are used.

Another advantage gained by some patented forms of tile is the use of a single shape to construct walls of various thickness.

Special tile are required for sills and window jambs, and in side construction for corners also, so that the ends of the cells will not be exposed. In one patented shape these special tile are cut from the regular tile by the mason with his trowel.

The standard shapes for side construction are shown in Fig. 44*a*. It will be noted that all of these tiles are 5 in. high and 12 in. long, and that three shapes are provided for use in the body of the wall; one $3\frac{3}{4}$ in. wide, one 8 in. wide with 2 cells, and one 8 in. wide with 3 cells. The jambs, sills and corners for use with standard tile are shown in Fig. 44*b*. The methods of building 8- and 12-in. walls using these tile are shown in Fig. 44*c*. A wall with a brick facing bonded with brick headers is shown in Fig. 44*d*, and one bonded with metal ties is shown in Fig. 44*e*. A stone facing is shown in Fig. 44*f*, and a terra cotta facing is shown in Fig. 44*g*.

[1] Technologic Paper of the Bureau of Standards, No. 311.

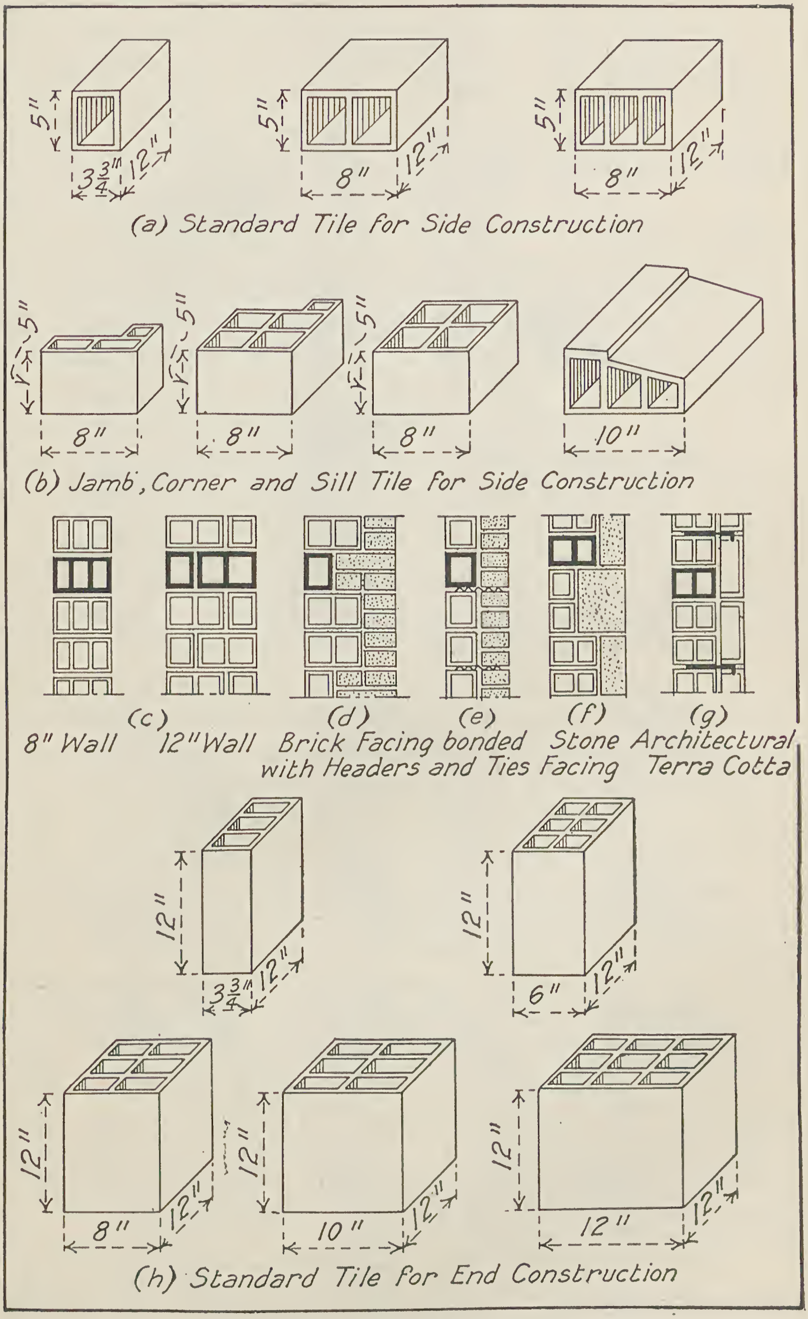



Fig. 44. Hollow Tile Shapes

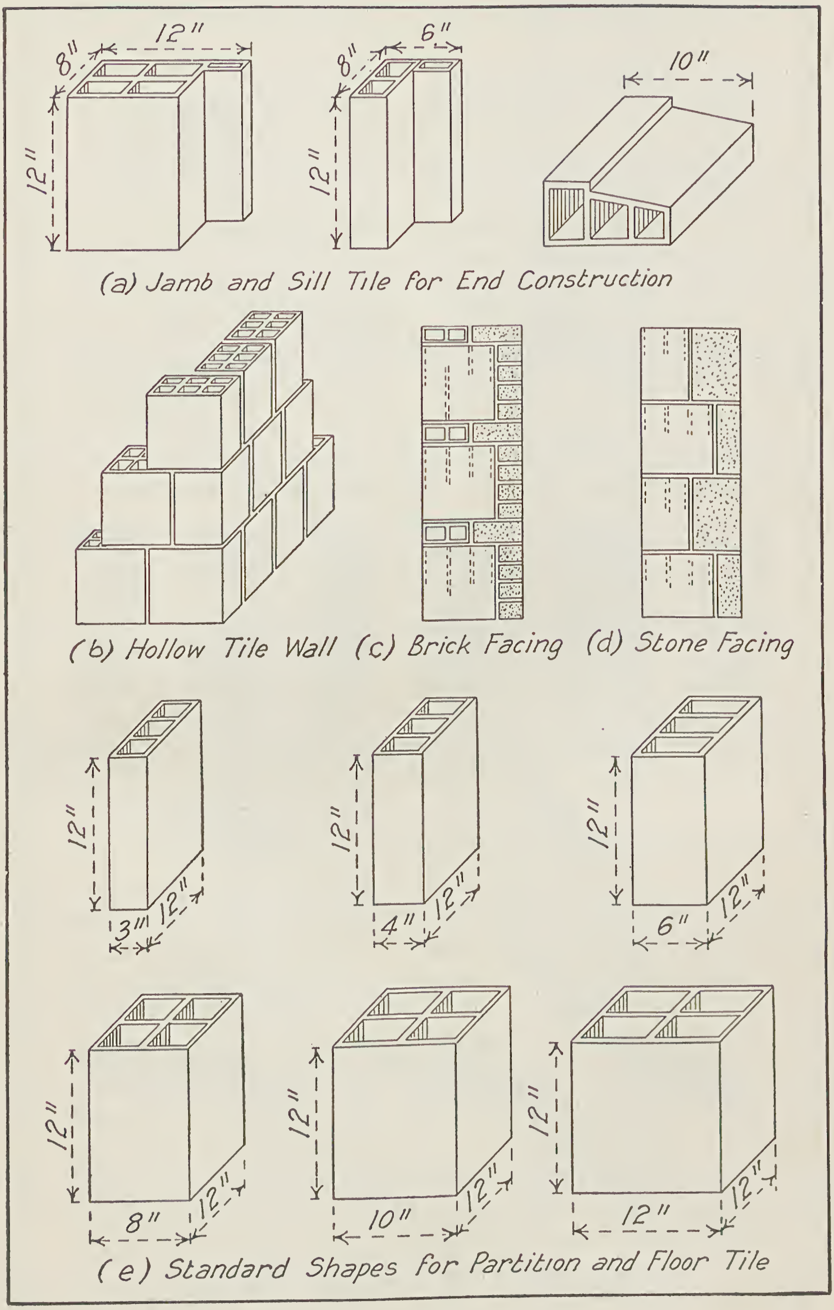



FIG. 45. Hollow Tile Shapes

The standard shapes for end construction are illustrated in Fig. 44*h*. The exposed face in all of these tiles is 12 in. by 12 in. The $3\frac{3}{4}$-in. width has 3 cells; the 6-in., 8-in., and 10-in. widths, 6 cells and the 12-in. width, 9 cells. The jambs and sills for use with standard tile are shown in Fig. 45*a*. The methods of building walls using these tile are shown in Fig. 45*b*. A wall with brick facing bonded with brick headers is shown in Fig. 45*c*. A stone facing is shown in Fig. 45*d*.

The standard shapes for partition and floor tile are shown in Fig. 45*e*. All of these tile have a 12-in. by 12-in. exposed face. The 3-in., 4-in., and 6-in. widths have 3 cells and the 8-in., 10-in., and 12-in. widths have 4 cells. These tiles are lighter than the end-construction tiles for bearing walls as shown in Fig. 44*h*. They are usually laid in partitions with cells vertical but the cells are often placed horizontal. For nonbearing partitions this practice is not objectionable.

The "Interlocking Tile" shown in Fig. 46*a* is a side-construction tile and is furnished in one size only, this size being used to construct 8-in. and 12-in. walls as shown in Fig. 46*b* and brick facing with brick header bond as shown in Fig. 46*c*. A brick or stone facing may be fastened with metal ties in the same manner as that shown for standard side-construction tile in Fig. 44*e*. Special shapes are made for corners, jambs and sills.

The "Load Bearing Tile" shown in Fig. 46*d* is a side-construction tile. It is furnished in several heights 4 in. and 8 in. wide. The 4-in. tiles may be ordered separately or they may be formed by splitting 8-in. tile on the job. The methods of constructing 8-in. and 12-in. walls are shown in Fig. 46*e*. A wall with a brick facing and brick header bond is shown in Fig. 46*f*. Special shapes are made for corners, jambs, and sills. Metal ties may be used in a manner similar to that shown in Fig. 44*e*.

The "Universal Unit Tile" as shown in Fig. 46*g* is a side-construction tile and is furnished in one size only, all of the special sizes and shapes being cut with a trowel from the regular shape leaving units of usable size. The methods of constructing 8-in. and 12-in. walls are shown in Fig. 46*h*. A wall with a brick facing and brick header bond is shown in Fig. 46*i*. Metal ties may be used as with other types.

Other patented forms of side-construction tile are the "Heavy Duty Tile" in Fig. 46*j*, the "Heath Tile" in Fig. 46*k*, the "Cordtex Tile" in Fig. 46*l*, the "Roman Tile" in Fig. 46*m*, and the "Pentex Tile" in Fig. 46*n*. The last three patterns have a special face to be used on exterior walls without stucco. The method of constructing an 8-in. wall with "Pentex Tile" is shown in Fig. 46*o*.

The special end-construction tile shown in Fig. 46*p* has a double center web so arranged that the vertical webs of each tile will line up

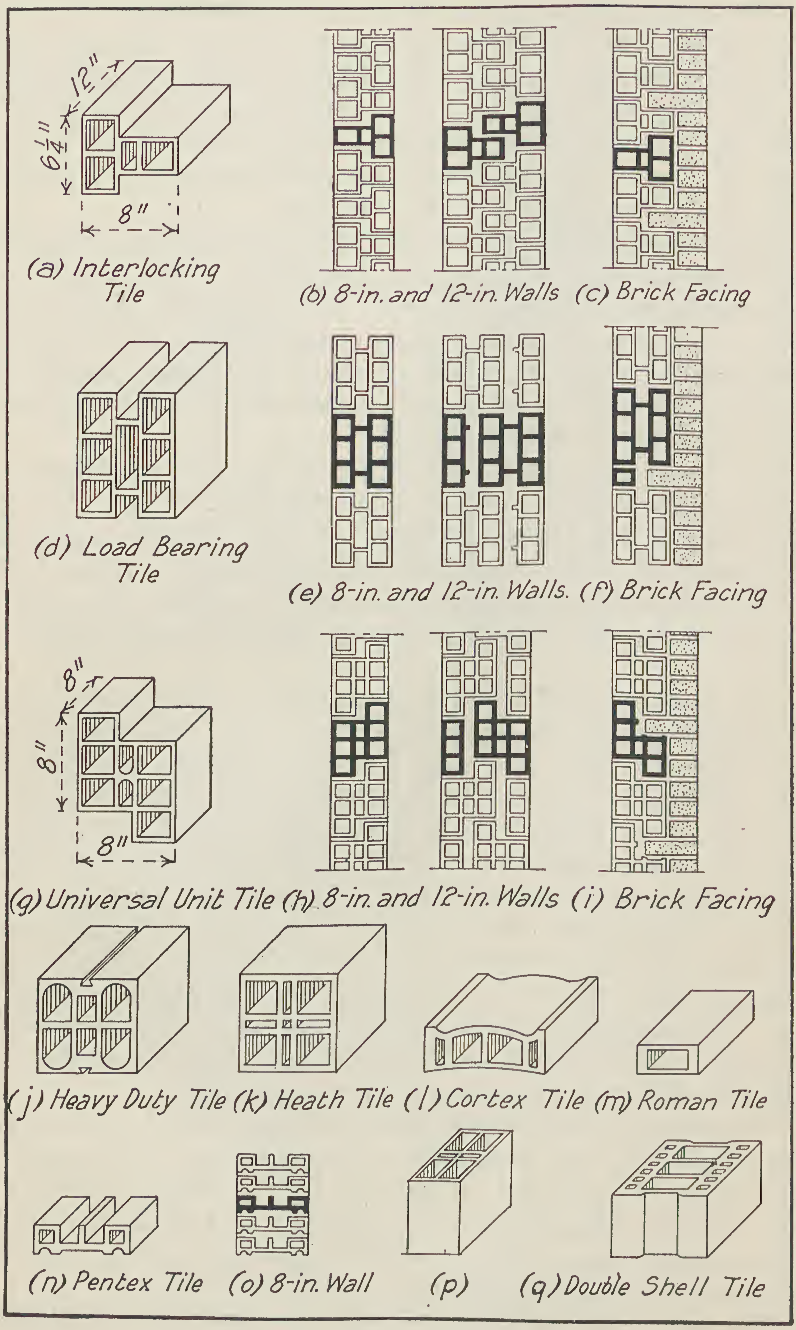



Fig. 46. Hollow Tile Shapes

with those of the tile below when the courses break joints in the center of the tile. In the standard shape the vertical webs are not aligned so that the full strength is not developed because only the shells bear directly on each other.

A "Double Shell" end-construction tile is shown in Fig. 46*q*. The vertical cross webs of these tile do not align when placed in a wall. The wide double shell gives a better surface for the horizontal joints than that secured with the single shell. These tile are intended for use in exterior walls without stucco. They are furnished unglazed with both surfaces combed, the better surface being used on the outside and the other surface on the inside for plaster. They are also furnished with a special rough glazed finish on the outside and dovetail scoring on the inside for plaster or with a smooth glazed finish on the inside for use without plaster in garages, factories, warehouses, etc.

**Hollow Concrete Block and Tile Shapes.** — *Concrete blocks* are made in a great variety of shapes. They are all of the end-construction types but have larger surfaces for the horizontal mortar joints than are available with most forms of end-construction hollow clay tile, the air spaces are cells occupying about one-third of the cross-section. The minimum thickness used for shells or webs is 2 in. The height is commonly 8 in. but varies from 8 in. to 16 in. in various types. The most common lengths are 16 and 24 in., but blocks 4 in. long are available in some types. Concrete blocks are usually intended to extend entirely through the wall, the common widths being 8, 10, and 12 in., but tiles as narrow as 2 in. and as wide as 20 in. are made. Simplified Practice Recommendation No. 32 of the Department of Commerce recommends that standard sizes of blocks be adopted, the height in all cases to be $7\frac{5}{8}$ in., the length $15\frac{5}{8}$ in., and the widths to be 6 in., 8 in., 10 in., and 12 in. These sizes will form units 8 in. high and 16 in. long when a $\frac{3}{8}$-in. mortar joint is used.

Various types of concrete blocks are shown in Figs. 47*a* to 47*f*. It will be noticed that these are of three general types. In one, the outer and inner shells are connected by webs, in another type the outer and inner shells are connected by metal ties, and in a third type the outer and inner shells are built up of separate blocks the two parts being held together by the cross bond of the projecting members corresponding to webs. Special blocks are made for corners, jambs, sills, etc. Concrete blocks are used for backing behind facings of brick and stone in the same manner as hollow clay tile.

*Concrete tile* are smaller and lighter in weight than concrete blocks. The cell walls are thinner and 40 per cent or more of volume of the tiles is air space. Concrete tile do not form as strong a wall as the blocks but the strength is sufficient for light bearing walls, partitions and for backing

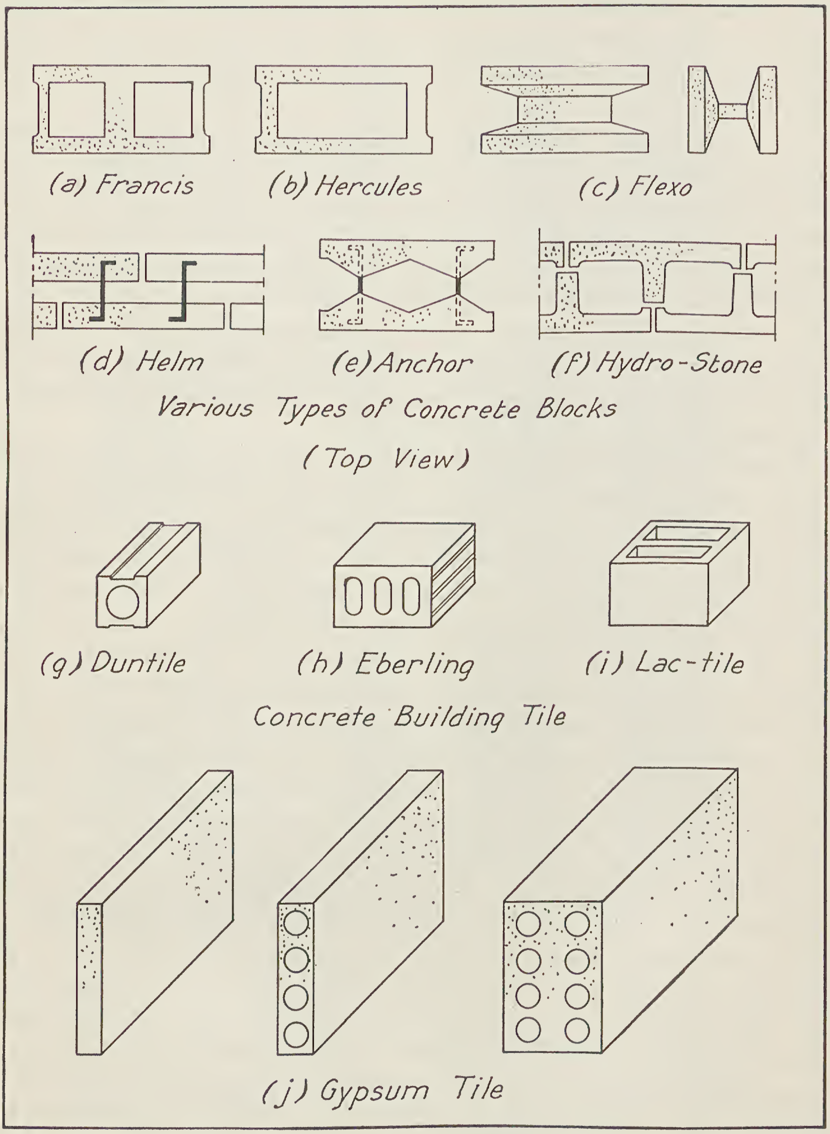



Fig. 47. Concrete Block and Tile, and Gypsum Tile

face stone or brick. The sizes of tile now in use vary in height from 3 in. to 8 in., in width from $3\frac{7}{8}$ in. to $17\frac{1}{2}$ in. and in length from 10 in. to 14 in. Simplified Practice Recommendation No. 32 of the Department of Commerce recommends that standard sizes of tile be adopted, the height in all cases to be 5 in., the length 12 in., and the widths to be $3\frac{3}{4}$, 8, and 12 in.

Three types of concrete tile are shown in Figs. 47*g*, *h*, and *i*.

**Gypsum Tile Shapes.** — Gypsum tile are 12 in. high and 30 in. long and vary in thickness from 2 in. to 8 in. as shown in Fig. 47*j*. The 2-in. tile is solid and the 3-in. tile is furnished either solid or with cells. The other tiles all have cells or core holes. The thickness of shells and webs should not be less than $\frac{3}{4}$ in.

**Furring.** — Furring is somewhat less necessary on exterior walls constructed of hollow tile and concrete blocks than in those constructed of brick, stone, or concrete because the air cells help to check the transmission of heat and moisture. However, mortar joints running through the wall are found to conduct moisture readily when poorly or incompletely made, and walls having such continuous joints should be furred in localities where furring is required by the severe climatic conditions.

Gypsum blocks have a high percentage of absorption, and when wet they lose a considerable part of their strength. They should not be used in contact with damp surfaces, or where likely to become wet.

Gypsum blocks are always placed with the long dimension horizontal.

**Surface Finish.** — Hollow clay tile may be obtained with or without a *salt glaze* surface. The surface of the unglazed tile may be smooth for use without plaster or stucco or *scored* to receive plaster or stucco, the dove-tail scoring shown in the illustrations of some of the shapes being very common. The glazed tile are always smooth and are made for use in outside walls or foundations without stucco or plaster. The glazed surface makes the tile impervious to water and therefore very durable. Tile are also made with special finishes on the exposed surface for use on exterior walls without stucco and where the appearance is an important factor.

The exterior surface of hollow clay tile and concrete block outside walls is commonly covered with stucco and interior surfaces with plaster as described in Article 80. A brick or stone face with hollow tile or concrete block backing may be used for exterior walls. The face brick may be bonded to the hollow tile or concrete block backing by using brick headers or metal ties. If stone facing is used it should be at least $3\frac{3}{4}$ in. thick. A $7\frac{1}{2}$-in. bonding course may be used to tie the face to the backing or metal ties may be used as with brick facing. For walls faced with stone see Article 19. If brick headers or stone bonding courses are used the entire wall may be considered in bearing and as effective thickness in meeting building code requirements, whereas if metal ties are used the brick facing can not be so considered for the two parts will not act as a unit.

The special surface treatment used on concrete building units to improve their appearance may be divided into the following classes:

(*a*) Special designs with beveled edges, margins or made to resemble some stone finish such as rock face. The imitations of stone finishes are not usually attractive.

(*b*) Washes or thin coatings of neat cement or cement paints. These may craze, dust, or change in color if not properly applied or selected.

(*c*) Exposed aggregates obtained by removing the surface film of cement. This may be done by means of a fine spray, supplemented with a brush, before the cement has set appreciably or by using a weak muriatic acid solution if the cement is permitted to harden slightly. If the cement has attained a considerable degree of hardness a wire brush may be used with muriatic acid. For concrete units which have hardened a carborundum stone or a sand blast may be used.

(*d*) Special aggregates and colors may be used in a facing. Some of the materials used for this purpose are colored marble chips, crushed granite and clay, mica, and even crushed glass. The special aggregates may be exposed as explained in (*c*). The coloring materials are usually mineral pigments. They should not be used in amounts much greater than 10 per cent of the cement on account of the reduction in strength which larger amounts may cause.

**Hollow Tile Floor Arches.** — Floors may consist of arches of specially designed hollow clay tile supported by steel beams. Hollow clay tile arches may be flat as shown in Fig. 48*a*, or segmental as shown in Fig. 48*b*. The *flat arch* provides a flat surface for the ceiling of the rooms below, and is preferred for that reason, but the *segmental arch* will develop greater strength than the flat arch of the same depth, and is more economical if a flat ceiling is not desired.

The thrust produced by the arches is taken care of by means of steel tie rods passing through the webs of the beams and held in position by nuts at each end. The spacing of the beams supporting tile arches should not exceed 8 ft.

Hard-burned or semi-porous tile are used for floor arches. The thickness of the shells and webs should not be less than $\frac{5}{8}$ in. Every tile should have at least one continuous vertical web for each 4 in. of width. The tile at the ends of the arch and resting against the beams are known as *skewbacks*. These skewbacks should be of such form and section as to fit the beams accurately and properly receive the thrust of the arches. Care must be used in securing a proper keying or bonding of the various rows of tile, and the tiles should always be set in cement mortar.

The rise of segmental arches should not be less than 1 in. for each foot of span, and the depth should be sufficient to carry the imposed load, but never less than 6 in. with at least 2 cells in this depth.

The depth of flat arches should be at least $1\frac{1}{2}$ in. for each foot of span,

not including any portion of the depth of tile that projects below the under side of the beams. The total depth should in no case be less than 9 in. and the tile should have at least 3 cells in that depth.

The tie rods should be of sufficient size to carry the imposed load, but they should never be less than $\frac{3}{4}$ in. in diameter, and their spacing should not exceed 8 times the depth of the beams which carry the arches, and should not be greater than 8 ft. in any case. They should be completely encased to a depth of 2 in. in fireproofing material extending into and anchored to the arch. Tie rods should be properly located to take the thrust of the arch and in general they should be placed as near the bottom flanges of the beams as practicable.

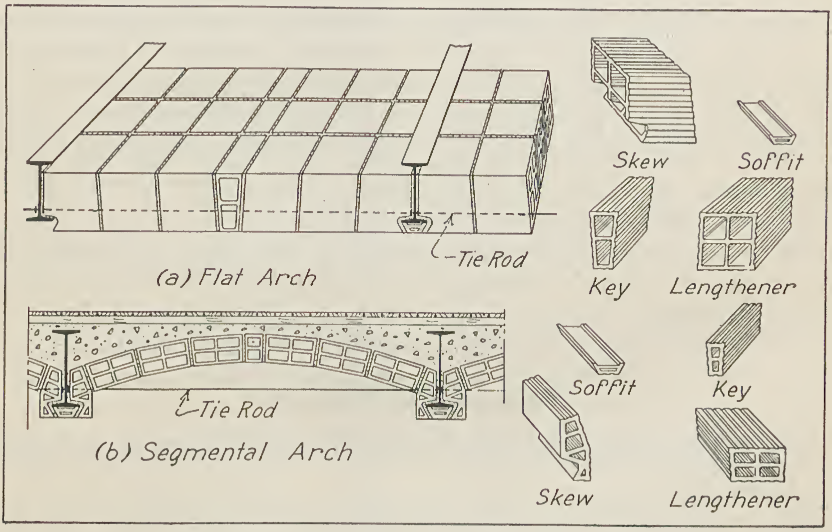



FIG. 48. Hollow Tile Floor Arches

The lower flanges of beams supporting hollow tile arches should be fireproofed by lugs which form part of the skewbacks and extend around the flanges meeting at the middle, or by tile slabs held in position by dove-tailed lugs projecting from the skewbacks as shown in Figs. 48*a* and *b*. In either case care should be taken to insure that all joints are solidly filled with mortar. If steel beams or girders project below the ceiling line, they are protected by specially shaped tile.

The space between the tops of the arches and the flooring is filled with cinder concrete consisting of one part portland cement to ten parts of cinders. The cinders must be hard, well-burned, vitreous clinkers, free from sulphide or fine ashes. Cinders from soft coal are likely to be unsatisfactory. Steel or iron pipes or other ferrous metal construction

when embedded in cinder concrete fill should be given a coating of neat cement grout, or be encased in cement or lime mortar as a protection against corrosion. If the finished floor is to be of wood, nailing strips are embedded in the cinder concrete.

Hollow tile arch floors are light and strong, and were at one time extensively used for steel framed buildings, but concrete ribbed slabs are largely used at the present time where tile arches would have been used a few years ago. It is evident that tile arches cannot be used advantageously with concrete beams.

**Quality of Material.** — The American Society for Testing Materials has adopted "Specifications for Hollow Burned Clay Load-bearing Wall Tile." These specifications divide hollow tile into three classes: hard, medium, and soft. The maximum permissible per cent of absorption for each class is given and the required compressive strength in pounds per sq. in. of the gross section for end-construction and for side-construction tile of each class is specified. Hard and medium tile which have been properly burned are considered as having satisfactory weathering resistance for exterior use but tile classed as soft is required to withstand a test consisting of 100 alternate freezings and thawings.

The quality of concrete blocks and tile is covered by "Specifications for Standard Concrete Building Units" as adopted by the American Concrete Institute.

### Minimum Wall Thickness

The factors which affect the thickness of masonry walls are discussed in Article 17.

The recommendations of the Building Code Committee of the Department of Commerce for hollow clay tile, concrete block, concrete tile walls and hollow walls of brick are as follows:

**Lateral Support.** — Walls of hollow tile or of concrete block or tile, and all hollow walls of brick shall be supported at right angles to the wall face at intervals not exceeding sixteen times the wall thickness in top stories, or eighteen times the wall thickness elsewhere. Such lateral support may be in the form of cross walls, piers, or buttresses when the limiting distance is horizontal, or by floors when the limiting distance is vertical. Sufficient bonding or anchorage shall be provided between the wall and the supports to resist the assumed wind force acting in an outward direction. Piers or buttresses relied upon for lateral support shall have sufficient strength and stability to transmit the wind force, acting in either direction, to the ground. When walls are dependent on floors for their lateral support provision shall be made in the building to transfer to the ground the lateral force resisted by all floors.

**Thickness and Height of Exterior Walls Other Than in Skeleton Construction.** — Walls of hollow tile, concrete block or tile, or hollow walls of brick shall not exceed 50 ft. in height above the top of foundation walls.

The thickness of walls of the above materials and types shall be sufficient at all points to keep the stresses due to combined live and dead loads for which the building is designed within the limits prescribed.

The minimum thickness of exterior walls of hollow tile, or concrete block or tile, or of hollow wall construction shall be 12 in. for the uppermost 35 ft. of their height, and at least 16 in. for the remaining lower portion; except that the top story wall of a building not exceeding three stories or 40 ft. in height, or the wall of a one-story commercial or industrial building may be 8 in. thick, provided that the roof beams are horizontal; and except that exterior walls of one and two family dwellings may be 8 in. thick for the uppermost 20 ft. When gable construction is used for such dwellings an additional 5 ft. is permitted to the peak of the gable.

Where walls are stiffened at distances not greater than 12 ft. by cross walls or by internal or external returns at least 2 ft. deep, the thickness may be 12 in. throughout, except that the top story, or for one and two family dwellings the uppermost 20 ft., may be 8 in. as previously provided.

**Bond.** — Where two or more hollow units are used to make up the thickness of a wall, the inner and outer courses shall be bonded at vertical intervals not exceeding three courses by lapping at least one cell completely over a cell of the unit below.

**Beam Supports.** — Suitable provision shall be made at each line of floor beams in hollow walls or walls of hollow units, to shut off the spaces above from those below, and to ensure good bearing for beams and uniform distribution of loads.

**Piers.** — Hollow tile or hollow concrete block or tile shall not be used for isolated piers unless solidly filled with concrete. The unsupported height of such piers shall not exceed 10 times their least horizontal dimension.

**Chases and Recesses.** — Chases and recesses in walls of hollow tile, hollow concrete block or tile, or in hollow walls of brick shall not exceed in extent those permitted for solid brick walls under the same conditions. Chases and recesses shall not be cut in walls of the above types, but may be built in. No chases or recesses shall be permitted in fire walls that will reduce the thickness below the minimum specified in this code.

**Fire Walls of Hollow Tile, Concrete Block or Concrete Tile, or of Hollow Wall Construction.** — Fire walls of hollow tile or concrete block or concrete tile shall be not less than 16 in. thick in any part, except that for residential buildings they may be not less than 12 in. thick throughout. Hollow walls of brick used as fire walls shall be not less than 12 in. thick throughout. No fire walls of the above types shall be broken into, subsequent to erection, for the insertion of structural members.

Where combustible or unprotected steel building members frame into hollow party or fire walls of thickness not greater than 12 in., they shall not project more than 4 in. into the wall and shall be so spaced that the distance between embedded ends is not less than 4 in. The space above, below, and between them shall be

filled solidly with burnt-clay materials, mortar, concrete, or equivalent fire-resistive material, to a depth of not less than 4 in. on all sides of the members.

All open cells in tile or blocks occurring at wall ends shall be filled solid with concrete for at least a depth of 6 in., or closure tile set in the opposite direction shall be used.

Party walls which function also as fire walls shall conform to requirements for fire walls.

**Fire Division Walls.** — Fire division walls of hollow tile, or of concrete block or tile, shall be not less than 12 in. thick in any part, and for buildings of storage and heavy manufacturing occupancy they shall be not less than 16 in. thick throughout. Hollow walls of brick used as fire division walls shall be not less than 12 in. thick throughout.

**Bearing Partitions.** — When not used as party, fire, or fire division walls, walls of hollow tile, concrete block or concrete tile, or hollow walls of brick shall be not less in thickness than one-eighteenth of the height between floors or floor beams.

**Nonbearing Partitions.** — Nonbearing partitions of hollow tile, concrete block or concrete tile, hollow walls of brick or of gypsum block or other similar materials shall be built solidly against floor and ceiling construction below and above, and shall not exceed the following unsupported heights:

| Thickness Exclusive of Plaster | Maximum Unsupported Height | Thickness Exclusive of Plaster | Maximum Unsupported Height |
|---|---|---|---|
| Inches | Feet | Inches | Feet |
| 2 | 8 | 6 | 20 |
| 3 | 12 | 8 | 25 |
| 4 | 15 | | |

**Panel and Inclosure Walls.** — The requirements for hollow tile, concrete block or tile walls or hollow walls of brick are the same as for brick walls and are given in Article 18.

## REFERENCES

Circular of the Bureau of Standards, No. 304, Properties and Manufacture of Concrete Building Units.

Hollow Tile Construction, by J. J. Cosgrove, Scientific Book Corp., 1921.

*Proceedings* of The American Concrete Institute.

## ARTICLE 21. ARCHITECTURAL TERRA COTTA

**Definitions.** — There are two general classes of terra cotta used in building construction: structural and architectural. *Structural terra cotta* includes hollow clay tile used in the construction of walls, partitions,

and floors as described in Articles 20 and 43, where the function of the tile is primarily structural rather than decorative as is the case with *architectural terra cotta.*

Architectural terra cotta is a burned-clay product molded to various shapes and finished with various colors and surface textures to form cornices, copings, wall trim, facing for masonry walls, and for many other decorative uses in buildings. Its use corresponds very closely with that of cut stone.

Architectural terra cotta is furnished in blocks the size of which is determined by requirements of architectural design and by the limitations of the process of manufacture. The greatest dimension does not often exceed 2 or 3 ft.

Architectural terra cotta is not a stock material but is manufactured to suit the special requirements of each building; however, a few types of window trim, copings, belt courses, cornices, and chimney tops are frequently carried in stock.

A facing of architectural terra cotta and a typical block used in the facing are illustrated in Fig. 49*a*; a cornice in Fig. 49*b*; and a wall coping in Fig. 49*c*.

**Material.** — The clays used in the manufacture of architectural terra cotta are carefully selected to provide the desired physical and chemical properties. As a rule, a mixture of clays is used to secure the proper plasticity and binding qualities before burning; to avoid excessive shrinkage and warping while burning; and to provide the necessary strength and durability after burning. The chemical reactions which occur during burning affect the color of the product, so must be considered in the selection of clays. The color on the exposed surface is secured by spraying the surface, before burning, with a liquid which has the proper chemical composition, as will be explained in another paragraph.

**Drawings.** — The architect's drawings must be redrawn and slightly enlarged to allow for a shrinkage of from $\frac{3}{4}$ in. to 1 in. per ft. which occurs in burning; to conform to the special requirements of the material and the process of manufacture; and to provide for jointing and anchoring. The drawings thus prepared are called *shop drawings.*

**Models.** — A model is made of each piece required except where several pieces are alike, in which case one model will serve for the several pieces. In making these models the shop drawings are followed. For plain work the models are made of plaster of paris in the plaster shop but ornamental modeling is done in plastic clay by skilled modelers and sculptors.

**Molds.** — Molds are made by surrounding the models with a mixture of plaster of paris and water. This mixture sets very quickly and the

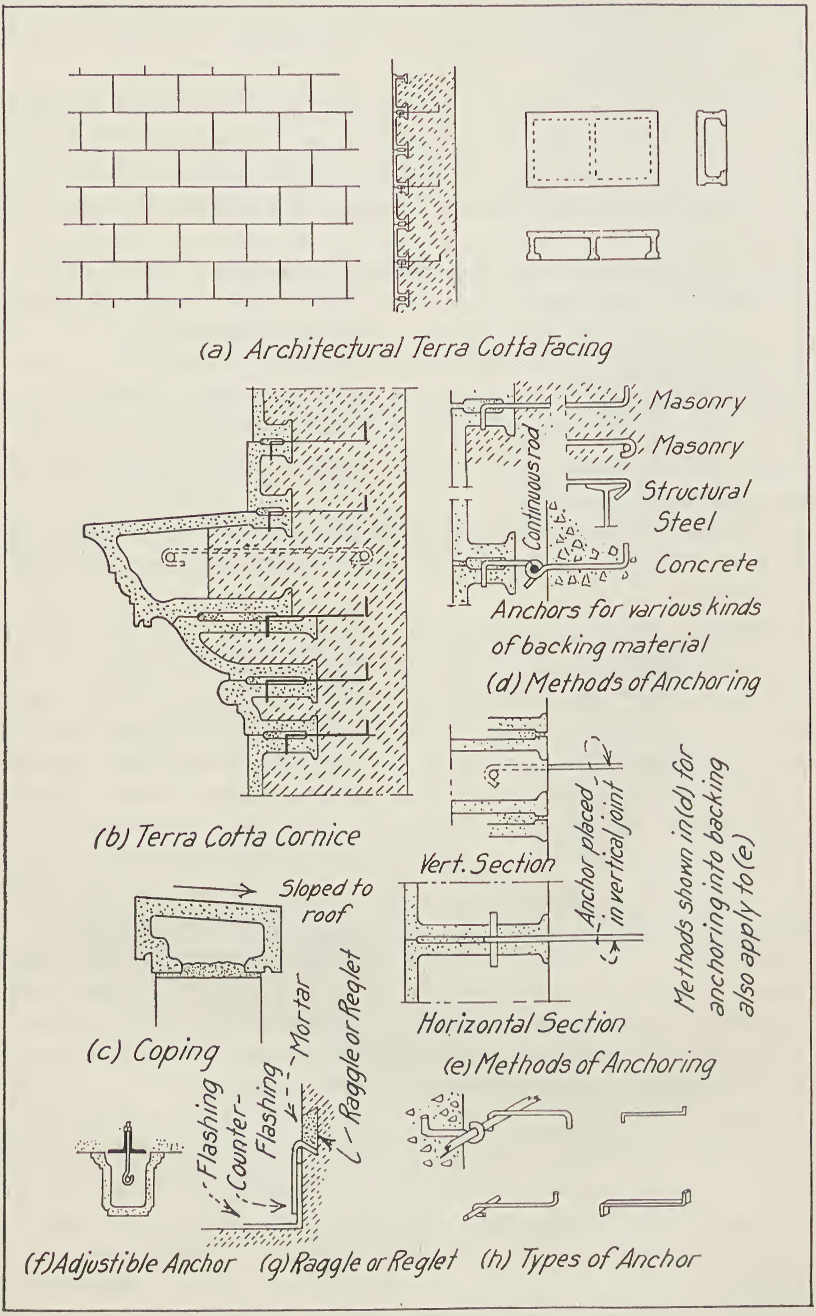



Fig. 49. Architectural Terra Cotta

model is removed from the mold, the joints necessary to permit this removal having been provided in the mold.

**Pressing.** — After the model has been removed the mold is taken to the pressing shop where plastic clay is pressed into the molds by hand to form the terra cotta blocks. The molds are not filled solid but the blocks are formed with walls or shells varying in thickness from 1 to 2 in. In order to provide greater strength, webs are put in at intervals to divide the hollow space in the interior of the tile into cells about 6 in. wide. Ordinarily the back of the tile or the side opposite to the exposed face is left open, the filling of the mold being accomplished from this side.

**Finishing.** — When sufficiently stiff the block is turned out on a drying board where it is finished; that is, mold seams are removed and the desired surface texture is provided.

**Drying.** — After the blocks are finished they are taken to drying rooms where the surplus moisture is evaporated, giving the blocks sufficient rigidity to permit handling and placing in the kilns.

**Spraying.** — After the drying process is completed the terra cotta blocks pass into the shipping or spraying department where, by means of compressed air apparatus, the surfaces which are to be exposed in the building are sprayed with a liquid mixture which during the burning process develops the desired color or glaze.

**Burning.** — When the spraying has been completed the blocks are placed in kilns where they are subjected to a temperature gradually rising to 2000 deg. fahr. or more. The kiln is then slowly cooled to normal. The time required to charge, fire, and discharge a kiln is about two weeks.

**Fitting.** — The terra cotta blocks are removed from the kilns and taken to the fitting floors where they are laid out and fitted together according to the position they are to occupy in the structure. When required, the joints are squared and cut or ground by hand or machine. Blocks which are to be placed in the lower stories of a building where they may be plainly seen must be more carefully fitted than those which are to be placed some distance above the ground where close inspection is not possible. The surfaces forming the joints are shaped as shown in Fig. 49*d* to facilitate grinding.

**Shipping and Storing.** — For rail transportation, terra cotta is shipped in bulk, securely packed in hay and braced on the cars to prevent shifting. Upon arrival at the building site the hay is removed and the terra cotta is placed in piles on wooden strips according to the order which it is to be required in the building. Each piece is numbered and its position determined by the corresponding number on the erection drawings supplied by the terra cotta manufacturer.

**Color.** — Practically any color can be obtained for the exposed surface of terra cotta. The body of the tile is usually the same for all surface colors, the different colors being obtained by spraying the surface with a suitable liquid mixture, as has already been explained. Several different colors can be produced on a single block with one burning by applying the proper materials to the surface. In this case a brush is used to apply the surface coat instead of the spray, or both may be used. This type of terra cotta is called polychrome.

**Surface Texture.** — There is practically no limit to the textures and surface treatments which may be obtained with terra cotta. The range extends from the natural clay finish, made impervious by a coating called a *slip*, through matt or dull to lustrous and brilliant glazes; and from a smooth or honed finish, through different degrees of tooling, dragging and stripping to any degree of roughness desired.

**Setting.** — Terra cotta should be set with all joints filled solid with portland cement mortar consisting of 1 part cement to 3 parts of sand and not more than $\frac{1}{5}$ of a sack of hydrated lime to each sack of cement.

**Backing.** — The backing of terra cotta should proceed simultaneously with the setting of the terra cotta and at no time should the terra cotta proceed more than one course ahead of brick backing. Each piece of terra cotta should be backed up solid with brick and mortar so as to make a perfect bond and homogeneous mass between wall lines. This backing will usually extend only to the wall line but should extend beyond the wall line when necessary for structural stability. Concrete is also used for backing.

**Pointing.** — Joints in terra cotta should be pointed and struck as the setting progresses, except in freezing weather. In freezing weather and when repointing is necessary, all joints should be raked or cut out to a depth of $\frac{1}{2}$ in. and pointed with the same mortar as that used in setting.

Joints in projecting cornices, overhanging terra cotta, balustrades, sill courses, and parapets should be raked out to a depth of $\frac{1}{2}$ in. and be pointed with elastic cement.

**Anchoring.** — Terra cotta may be used as a trim for walls of brick or stone masonry to which it is anchored with metal anchors; the entire exposed face may be of terra cotta anchored to a brick backing or bonded by blocks projecting into the backing; or terra cotta may be anchored to a structural steel or reinforced-concrete frame. Types of anchors are shown in Figs. 49*d*, *e*, *f*, and *h*.

Wherever possible, terra cotta blocks should be so designed that the use of metal anchors can be reduced to a minimum. This can be accomplished by bonding the blocks into the brick backing in a manner similar to that explained in Article 19 for stone facing. If the use of

metal ties is unavoidable they must be of sufficient strength and must be effectively protected from corrosion.

Anchors may be made of wrought iron or steel protected against corrosion by a coating of some kind. The following materials are used for the coating: Asphaltum, applied hot; red lead; zinc, applied by the processes of galvanizing, and sherardizing; and cadmium, by the Udylite Process. The coatings of asphaltum or red lead, and the embedding in mortar have not given satisfactory protection but the other processes may be depended upon.

These anchors have one end securely bedded in the backing or fastened to the structural frame and the other end bent down into an anchor hole in the terra cotta and passing through the mortar joint as shown in Fig. 49*d* or bent around a dowel which fits into holes provided in the sides of the terra cotta blocks on each side of a vertical joint as shown in Fig. 49*e*. The first method is used for blocks which are balanced on the wall and require a minimum amount of anchoring, whereas the second method is used for overhanging or suspended blocks which are not balanced on the wall but depend entirely, or to a large degree, on the anchor for their support.

Self-supporting courses which are balanced on the wall should be anchored to the framing or masonry by strap anchors of $\frac{1}{4}$-in. square iron cut and bent to proper size at the building and built into the joints.

All courses which are not self-supporting should be anchored with dowels and hangers, the size varying from $\frac{5}{8}$-in. dowels with $\frac{1}{2}$-in. hangers to $\frac{7}{8}$-in. dowels with $\frac{3}{4}$-in. hangers depending upon the size of the block to be anchored.

Methods used in anchoring terra cotta blocks to masonry backing are illustrated in Figs. 49*d* and *e*. An adjustable anchor is shown in Fig. 49*f*.

**Washes, Weep Holes and Drips.** — Washes should be provided on all projecting courses as illustrated in Fig. 49*b* and saddles should be provided in ornamental details sufficient to shed water readily. If voids in which water is liable to accumulate remain in the terra cotta after it is backed up and bonded properly and all supporting iron has been encased, then weep holes should be provided at such points as may be necessary for drainage and air circulation. All projecting courses, such as sills, belts, cornices, and copings, should have drips as illustrated in Fig. 49*c* so that water will not run down the face of the wall.

**Raggles for Flashing.** — Raggles, or reglets not less than $\frac{3}{4}$ in. deep should be provided in terra cotta to receive flashing, as shown in Fig. 49*g* where the terra cotta pitches inward against superimposed work; for all balcony floors; for all gutter linings and in other similar positions.

**Cleaning.** — After the terra cotta work has been completed it is cleaned down with soap and water or in some cases with a weak muriatic acid solution. Metal scrapers or brushes should never be used.

**Wall Thickness.** — According to the Building Code of the National Board of Fire Underwriters, architectural terra cotta facing should be at least 4 in. thick. Where every alternate course of facing is at least 8 in. thick and bonded into the backing at least 4 in. (which is not usually the case) the facing may be counted as a part of the thickness of the wall. No wall faced with terra cotta should be less than 12 in. thick. Wall thicknesses are required to be the same as for brick walls as given in Article 18.

**References.** — In preparing this article the publications of the National Terra Cotta Society have been of great assistance, particularly the booklet entitled *Terra Cotta Defined* and the book on *Standard Construction.* The paragraphs on Setting, Backing, Anchors, Pointing, etc., have followed the booklet entitled *A Terra Cotta Specification.*

## ARTICLE 22. CONCRETE MASONRY

**Uses.** — Concrete has largely replaced stone and brick for foundation walls for it is more durable than brick masonry, usually cheaper than stone masonry, and more substantial and watertight than either. Bearing walls above ground are not usually constructed of concrete for there is little if any advantage in cost over brickwork and concrete is unattractive unless special attention is given to the construction of forms and the placing of the concrete to secure a surface with few defects or objectionable form marks. During recent years there has been considerable development in the architectural treatment of concrete.[1] Attractive buildings with concrete exterior walls are being constructed. In some, the exposed surfaces are left as they come from the forms, with very little touching up, while in others special surface treatments are used.

When the interior of the building is to be of reinforced-concrete construction the usual practice is to use, except for low buildings, the skeleton type of building with wall columns and beams, and enclosure walls of concrete, brick, or hollow tile. This article will deal only with concrete walls, the other types having been considered in other articles.

Concrete is used to a limited extent in constructing bearing partitions and fire walls but it is not usually suitable for nonbearing partitions on account of its weight, the cost of forms, and the difficulty of installing after the floors are in place. Concrete partitions cannot be poured

[1] Reinforced Concrete Walls for Buildings, by W. E. Hart. *Proceedings* of American Concrete Institute, Vol. XXIV, p. 123.

much thinner than 4 in., therefore other forms of construction, being hollow and in some cases thinner, have a distinct advantage in weight and are at least as satisfactory in other respects, including cost.

**Concrete Foundations or Basement Walls.** — Foundation or exterior basement walls may be of five types. The simplest type is that shown in Fig. 50*a* which supports the vertical load for walls above and withstands the lateral pressure of the earth. Ordinarily the earth pressure is not considered in this type of construction because its effect is small as compared with that of the vertical loads but for low buildings with deep basements the earth pressure may be an important factor in design. Walls of this type are frequently constructed without reinforcement except that in the footings, but longitudinal reinforcement is desirable to reduce the danger of objectionable cracking due to temperature changes or uneven settlement. This reinforcement is placed near the top of the wall and near the bottom, just above the footings. Longitudinal reinforcement placed in the footings is not effective in the beam action of the wall because of the construction joint which always exists between the footing and the wall. If special provision needs to be made for earth pressure the wall may be made thicker than would otherwise be necessary or steel reinforcement may be placed vertically near the inner surface of the wall so that the wall will act as a vertical slab supported at the bottom by the basement floor and at the top by the first floor.

The type shown in Fig. 50*b* is designed to carry the concentrated loads of columns instead of the uniform load of a wall as in the case just discussed. Since there is now a definite beam action the wall must be designed as a continuous reinforced-concrete beam. The effect of earth pressure and the provisions for such pressure are the same as in the walls of the first type.

Instead of resting the columns on a bearing wall they may be carried down to a continuous footing as shown in Fig. 50*c*. The walls are now required to carry only the lateral earth pressure and possibly a load contributed by the first floor. The lateral earth pressure may be provided for by reinforcing the wall as a vertical slab supported by the basement floor and by the first floor as shown in the figure, or the main reinforcement may be placed horizontally, the necessary support being provided by the columns.

In Fig. 51*a* the columns are carried on independent footings and the wall carries only the lateral earth pressure and possibly a load contributed by the first floor. In this case the wall is designed as a vertical slab supported at the top by the first floor and at the bottom by the basement floor, the main reinforcement being placed vertically and near the

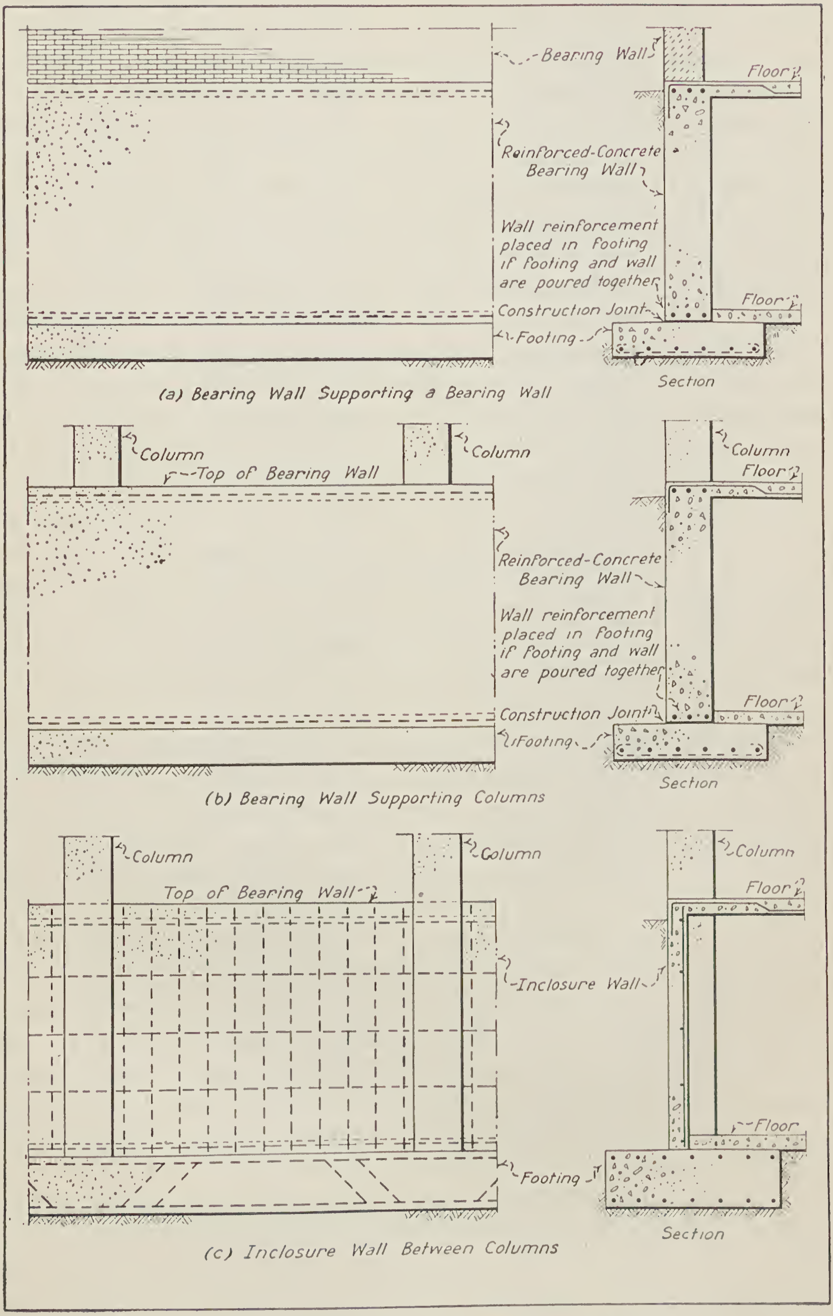



FIG. 50. Reinforced-concrete Foundation Walls

inner face. In Fig. 51*b* the wall is considered as supported by the columns and the main reinforcement is placed horizontally near the inner face. Windows or other openings in the wall will determine the most desirable method of support or, in some cases, it may be economical to design the wall as a slab supported on four sides.

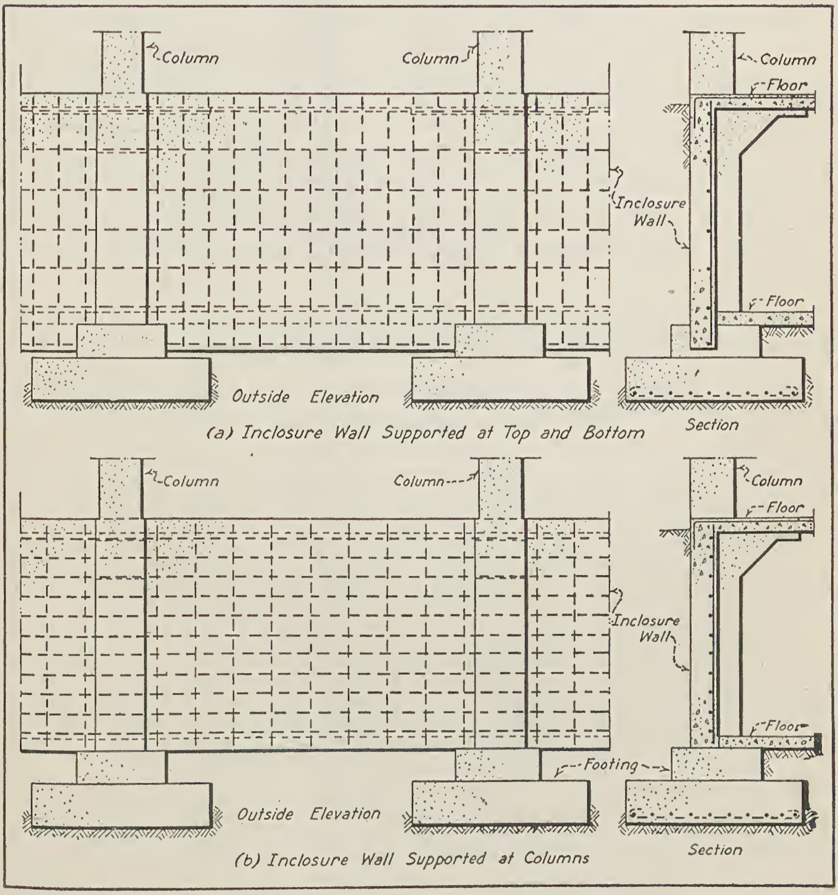



FIG. 51. Reinforced-concrete Foundation Walls

The use of caisson cofferdams for the basement walls of larger buildings is described in Article 14, and illustrated in Fig. 19.

**Plain and Reinforced-concrete Walls.** — All walls constructed of concrete should contain some reinforcement to provide against cracks due to temperature changes or unequal settlement. Building codes divide concrete walls into two classes: plain or reinforced. Walls which have less than $\frac{2}{10}$ of 1 per cent of reinforcement are classed as plain

concrete walls whereas those with that amount or more are classed as reinforced-concrete walls.

**Plain Concrete Walls Above Ground.** — Bearing and nonbearing walls above ground may be constructed of plain concrete without steel reinforcement but to avoid cracks due to settlement and changes of temperature it is desirable to use some reinforcement, particularly at corners and around openings. Horizontal reinforcement is much more essential than vertical reinforcement. In exterior walls classed as plain concrete, it is frequently desirable to place a band consisting of one or two bars all around the building just above the window openings and another band just below these openings. It is also desirable to place a similar band of steel near the top of the wall. Diagonal bars at the corners of openings are effective in preventing cracks and vertical bars at the sides used in connection with horizontal bars above and below the openings are desirable.

The Building Code Committee of the Department of Commerce makes the following comments concerning hollow walls of plain concrete:[1]

Several systems of construction are used which produce hollow or double walls of plain concrete. Usually there are two shells, each 3 or 4 in. thick, with an air space between. The inner and outer parts of such walls generally are tied together with wires or metal strips sufficient for stability in small dwellings, but if the area of both walls is needed for compressive strength and stability, positive means is required to bring them into common action. Unless some device or method adequate to do this is provided, the use of such walls for commercial structures over two stories in height or residences more than three stories is not advocated.

It is recognized that a hollow wall of plain concrete having the same net cross-sectional area as one of concrete block would be somewhat thicker. It may be said, however, that concrete block are better controlled as to quality, and their action under load is better known at this time than that of hollow concrete walls.

**Reinforced-concrete Walls Above Ground.** — Reinforced concrete is extensively used for panel walls in skeleton construction and to a lesser degree for bearing and nonbearing walls. Those walls should be reinforced with small steel bars placed horizontally and vertically and spaced from 12 to 18 in. apart, as shown in Fig. 52. Additional reinforcement should be placed around all openings and at points of concentrated loading. The reinforcement around openings should preferably be made continuous in both directions. The piers between openings should be provided with ties perpendicular to the face of the wall. Reinforced-concrete bearing walls have been used up to 10 stories in height for buildings with an interior framing of reinforced concrete.[2]

[1] Recommended Minimum Requirements for Masonry Wall Construction.

[2] *Engineering-News Record,* Vol. 101, p. 171.

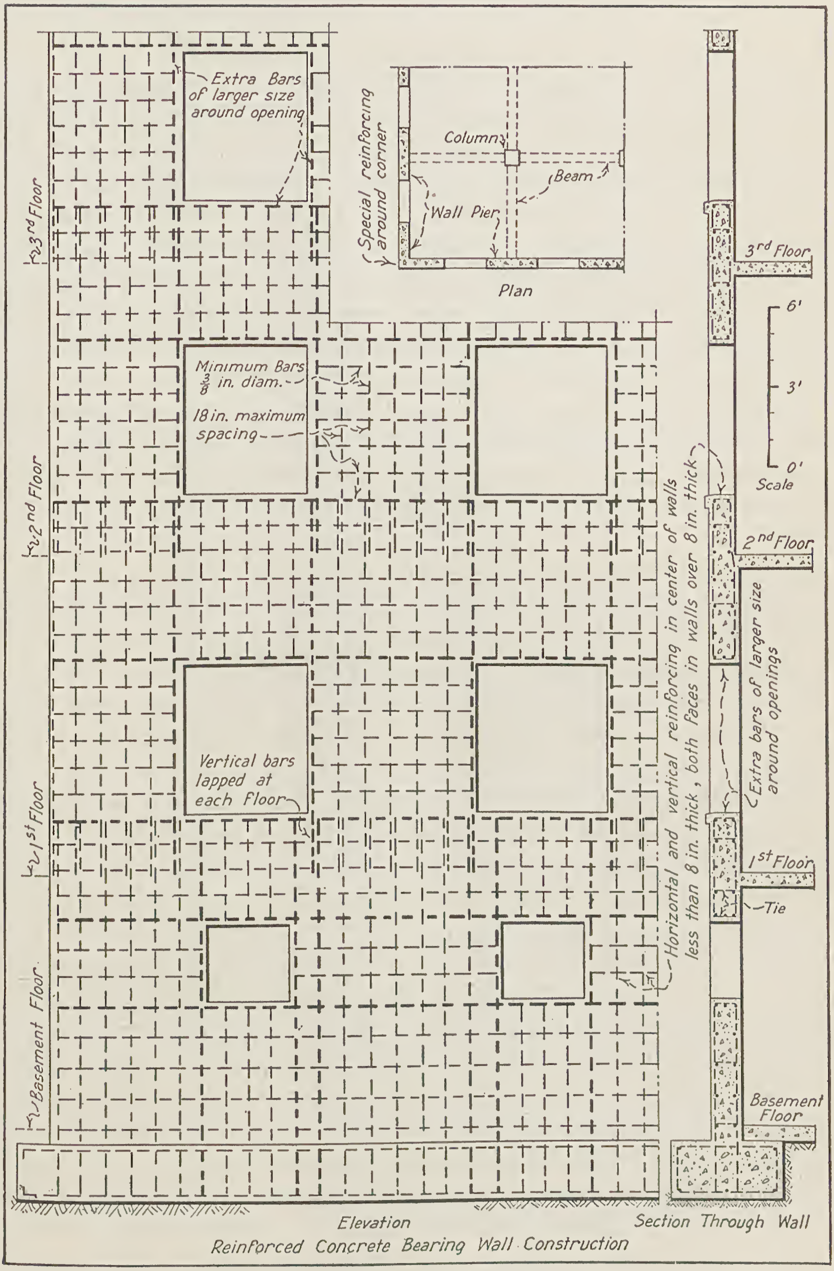



FIG. 52. Reinforced-concrete Bearing Walls

In skeleton construction the exterior walls rest on wall beams and are carried by the structural frame. They are called panel walls and are usually installed after the structural frame is completed.

Panel walls are required to carry only the wind pressure, so their thickness is usually determined by the minimum thickness which can be poured and which will be watertight. The thickness should never be less than 4 in. and will rarely be over 12 in. Enclosure walls should be reinforced with wire fabric or small rods placed from 12 to 18 in. apart running horizontally and vertically. They are not always tied to the structural frame but may be held in place by fitting into channels left in the columns. A weather-tight joint between the column and the wall is secured by a metal diaphragm or by other methods. A turned-up spandrel beam may serve as a panel wall.

**Partitions.** — Concrete is not used extensively in constructing partitions, other types having been found to be more suitable. When concrete partitions are used they should be at least 3 in. thick and should be reinforced both horizontally and vertically with light steel rods or wire fabric.

The Building Code of New York City requires that concrete partitions in fireproof buildings be at least 3 in. thick if properly reinforced with steel and at least 4 in. thick if not so reinforced. If cinder concrete is used those minimums are 4 in. and 5 in. respectively.

**Exterior Surface Treatment.** — The following discussion concerning surface treatment is abstracted from a report of the Committee on Concrete Surfaces of the American Concrete Institute:[1]

This recommended practice is designed to outline approved methods of treating the exterior surfaces of concrete factories, warehouses, and other industrial buildings in such a manner as to produce pleasing and durable surfaces at costs which are not inconsistent with the occupancy and surroundings of such buildings.

Good exterior appearance of concrete buildings depends fundamentally on care in the building of forms. Boards used in column forms should always run vertically and in beams and walls horizontally. Sound, clean lumber of sufficient strength should be used and the forms should be properly braced. The concrete should be carefully proportioned, mixed, and placed in order to reduce to a minimum the need of pointing, patching and other corrective treatments.

The surface treatments to be considered will be divided into the following five general classes:

(*a*) Pointing and patching (minimum requirements).

(*b*) Correction of column and beam lines, fill joints, etc.

[1] *Proceedings* of American Concrete Institute, Vol. XXI, p. 564.

(*c*) Cement washes and proprietary paints.
(*d*) Rubbed finishes.
(*e*) Tooled finishes.

The recommended methods for producing these finishes are given in the following paragraphs.

In *pointing and patching*, all nails, wires and bolts should first be removed or cut back to a depth of at least one inch from the surface of the concrete to provide a sufficient key for the pointing mortar and to insure against water reaching any pieces of iron or steel and causing rust spots or spalling. Bolt holes should be filled with corks with heads driven one inch back from the surface. Before pointing, all defective places should be thoroughly cleaned and saturated with water. A mortar of one part cement and two parts of clean building sand should then be forced into all parts of the cavity or defective spot, and the surface rubbed with a cork or wood float. If large patches of considerable depth and area occur, the mortar should be applied in two or more coats. Each under coat should be scored but it is not necessary or desirable for each coat to become entirely dry before applying the next.

Patching should be avoided in hot sunshine or a quick-drying wind, unless it is feasible to protect the fresh mortar with wet burlap or canvas.

*Correction of beam and column lines, fill joints*, etc. may be carried out in addition to pointing and patching to secure a better appearance. If reinforcement is detected near the surface special precaution should be taken to protect the steel from rust which will stain the concrete and eventually cause it to spall off. Beams which sag and bulge, and columns which are out of plumb should be cut to line. Nail head marks, fins, and other small projections should be removed. For such work pounding with a flat-headed hammer is more effective than cutting with a chisel. Fill lines (existing between separate pourings) should be dressed by thoroughly cleaning the joint and applying mortar and finishing with a cork or wood float.

*Cement washes* of practically any color from white or cream to gray can be prepared by varying the proportion of white or gray cement and light or dark sand. A mixture of 1 part white cement and 1 part finely screened yellow sand, with 5 per cent hydrated lime (by volume of cement) will give a serviceable color just off the white and will serve as a typical dry mixture. The dry batch should be large enough for a full day's work, but only enough wash should be prepared to last 1 hour. Before applying the wash, all pointing and patching should be completed. The area to be coated should first be thoroughly wet and then a full brush coat of wash applied. This coat should be rubbed in with a cork float, the surface being sprinkled with a little additional water if

necessary. Finally, the surface should be gone over with a clean, damp brush, brushing in the direction of the board marks. In this process all excess material should be removed, and the remaining coat should be as thin as will permit the surface to be entirely covered. In warm or drying weather the finished surface should be sprinkled once a day for 3 days and in cool, damp weather it should be sprinkled at least once within 24 hours after finishing. Many proprietary cement paints are on the market some of which have given satisfaction.

*Rubbed finishes* are obtained with carborundum stones. The first rub should be completed as soon as the forms can be removed. Faces of columns, beams, and walls should be treated within 3 or 4 days. As soon as the forms are removed the surface should be thoroughly wetted and then rubbed with a No. 20 carborundum stone. The rubbing will remove fins, board marks, and nail-head marks and to a certain extent the irregularities between boards. The cement paste which works in the rubbing process should be removed by washing and brushing. Voids in the concrete should be filled with mortar (usually 1 to 2) composed of finely screened aggregate of the same general description as that used in the concrete. This mortar should be thoroughly worked into the face with a carborundum stone. The second rub should be applied near the end of the work, when the building is ready to clean down and the danger of staining from other work is passed. The surface should be thoroughly wet and then gone over with a No. 24 carborundum stone. The paste which is worked up should be removed with a wet brush or clean bagging. When dry the finished surface will resemble limestone in color and texture.

*Tooled finishes* as used here include all finishes in which the surface of the concrete is mechanically roughened, or removed to expose the aggregate. Wire or fiber brushes, stone dressing tools, the sand blast, and rotary cutters are used for this purpose. The success of tooling depends upon the uniformity in the results obtained and therefore special attention is called to the importance of avoiding joints, fill lines, laitance, and segregation. Careful selection of aggregate helps in attaining the desired uniformity, and if the aggregate is selected for color, its exposure by tooling will introduce effects in color variation, as well as in texture. The effects produced by tooling are the most pleasing of any but at the same time are the most costly and difficult to do.

The brushed finishes should be executed immediately after the removal of the forms and if possible within 18 hours of the time the concrete is placed. The surface film of cement is removed by scrubbing the "green" concrete surface with fiber brushes and water. If the surface is too hard for fiber brushes, wire brushes followed by fiber brushes may be used.

Surfaces which are to be finished with the bush-hammer, the crandall, or similar tools should be at least two weeks old before treatment. The tools may be operated by hand or mechanically. After the tooling is completed the roughened surface is brushed with a fiber brush or washed with a hose stream to remove loose particles and dust.

See Article 19 for surface finishes used on cast stone, and Article 20 for those used on concrete blocks.

**Waterproofing:** see Articles 16 and 19.

**Efflorescence:** see Article 18.

### Minimum Thicknesses For Plain Concrete Walls

The factors which affect the thickness of masonry walls are discussed in Article 17.

The recommendations of the Building Code Committee of the Department of Commerce for plain concrete walls are as follows:

**Concrete Materials.** — Monolithic concrete construction containing not more than two-tenths of 1 per cent of reinforcement shall be classed as plain concrete.

Materials for bearing walls and piers of plain concrete shall be mixed in proportions of 1 part of portland cement to not more than 3 parts of sand and 5 parts of coarse aggregate, by volume, or a mixture of fine and coarse aggregates giving an equivalent strength and density.

**Lateral Support.** — Plain concrete walls shall be supported at right angles to the wall face at intervals of not exceeding twenty times the wall thickness. Such lateral support may be in the form of cross walls, piers, or buttresses when the limiting spacing is horizontal, or by floors when the limiting distance is vertical. Sufficient bonding or anchorage shall be provided between the wall and the supports to resist the assumed wind force acting in an outward direction. Piers or buttresses relied upon for lateral support shall have sufficient strength and stability to transfer the wind force, acting in either direction, to the ground. When walls are dependent upon floors for their lateral support provision shall be made in the building to transfer the lateral force resisted by all floors to the ground.

**Thickness of Walls.** — The minimum thickness of plain concrete bearing walls shall be 10 in. for the uppermost 35 ft. of their height and shall be increased 4 in. for each successive 35 ft. or fraction thereof, measured downward from the top of the wall, except that the top-story wall of a building not exceeding three stories or 40 ft. in height, or the wall of a one-story commercial or industrial building may be 8 in. thick, provided that such 8-in. wall does not exceed 12 ft. unsupported height and that the roof beams are horizontal, and except that exterior bearing walls of one and two family dwellings may be 6 in. thick when not more than 30 ft. in height. When gable construction is used for such dwellings an additional 5 ft. is permitted to the peak of the gable.

When plain concrete bearing walls of buildings more than three stories high

are stiffened at points not more than 12 ft. apart by cross walls, or by internal or external offsets or returns at least 2 ft. deep, they may be 10 in. thick for the uppermost 70 ft. of their height and shall be increased 4 in. in thickness for each successive 70 ft. or fraction thereof.

The minimum thickness of plain concrete exterior nonbearing walls shall be 10 in. for the uppermost 70 ft. of their height, and shall be increased 4 in. for each successive 35 ft. or fraction thereof, measured downward from the top of the wall; except that the top-story wall of a building not exceeding three stories or 40 ft. in height, or the wall of a one-story commercial or industrial building may be 8 in. thick, provided that such 8-inch wall does not exceed 12 ft. unsupported height, and that the roof beams are horizontal; and except that exterior nonbearing walls of one and two family dwellings may be 6 in. thick when not more than 30 ft. in height. When gable construction is used for such dwellings an additional 5 ft. is permitted to the peak of the gable.

Hollow monolithic walls of plain concrete shall have the same net cross-sectional area of material, irrespective of the space within the wall, as required for solid walls. The inner and outer parts of such walls shall be securely braced and tied together with noncorrodible ties or other means to bring them into common action. Where floor and roof systems are carried by such walls, provision shall be made for the distribution of these loads to the full cross-section of the wall.

**Reinforcement.** — Reinforcement, not less than two-tenths of 1 per cent computed on a vertical height of 12 in. shall be placed over all wall openings and at corners of the structure to prevent cracks. Floor and roof connection details shall be designed to transmit safely the vertical and horizontal loads imposed.

**Piers.** — The unsupported height of isolated piers of plain concrete shall not exceed ten times their least dimension.

**Chases and Recesses.** — Chases and recesses in plain concrete walls shall not exceed in extent those permitted for solid brick walls under the same conditions.

**Fire Walls.** — Same requirements as for brick walls as given in Article 18 except that plain concrete fire walls for buildings of residential occupancy may be 8 in. thick throughout.

**Fire Division Walls.** — Same requirements as for brick walls as given in Article 18.

**Panel and Inclosure Walls.** — Same requirements as for brick walls as given in Article 18.

## Minimum Thickness and Other Requirements for Reinforced-Concrete Walls

The Tentative Building Regulations for Reinforced Concrete of the American Concrete Institute[1] contain the following requirements for reinforced-concrete walls:

(*a*) Reinforced-concrete bearing walls shall have a thickness of at least one-twenty-fifth of the unsupported height or width, provided, however, that approved buttresses, built-in columns, or piers, designed to carry all the vertical loads, may be used in lieu of greater thicknesses. (Working stresses in such walls must not exceed the allowable values.)

(*b*) The lateral support for such walls shall consist of a fire-resistive floor when the framing is on one side of the wall only, but may be of a fire-resistive or of a non-fire-resistive type where framing is on both sides of the wall, provided that for residences, wood-frame construction properly tied may be used as support.

(*c*) In fire-resistive buildings, reinforced-concrete bearing walls shall have a thickness at least equal to the values shown in the table of minimum wall thickness given at the end of this section, except that exterior basement walls shall not be less than 8 in. thick.

(*d*) In fire-resistive buildings, bearing walls shall be reinforced with an area of steel in each direction, vertical and horizontal, at least equal to 0.0025 times the cross-sectional area. Walls 8 in. or more in thickness shall have half the steel at each face of the wall. The bars shall not be farther apart in either direction than 18 in., regardless of whether the steel is disposed in one or two layers, nor shall less than the equivalent of $\frac{3}{8}$-in. round bars be so used. The vertical steel shall not be relied on to carry load unless tied and arranged as in reinforced-concrete columns.

(*e*) All bearing walls shall be designed for any lateral pressure to which they are subjected. Eccentric loads and wind stresses shall be fully provided for. In such designs, the stresses for flexure shall govern.

(*f*) In non-fire-resistive buildings, exterior bearing walls may be of reinforced concrete, subject to the provisions of this section, when increased 50 per cent in thickness over those referred to in (*c*). In such walls, the amount of reinforcement in each direction, horizontal and vertical, shall be at least 0.002 times the cross-sectional area. The steel shall be distributed half to each face of the wall with a maximum bar spacing of 24 in.

(*g*) In buildings of skeleton construction, panel or other walls supported on the structural frame shall not be less than 5 in. thick, nor less than one-thirtieth of the horizontal distance between columns, cross walls, or equivalent anchorage. Such walls shall be reinforced in the same manner as bearing walls in fireproof buildings (see (*d*) above).

(*h*) Stairway and elevator enclosures in all classes of buildings may be built of

[1] *Proceedings* of The American Concrete Institute, Vol. XXIV, p. 825.

reinforced concrete, when the wall thickness are in accordance with the requirements of (*c*) and (*g*) and reinforcement in accordance with (*d*).

MINIMUM WALL THICKNESS, IN INCHES, IN STORY INDICATED

| No. of Stories | Basement | 1st | 2nd | 3rd | 4th | 5th | 6th | 7th | 8th | 9th | 10th |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 6 | 6 | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 2 | 7 | 6 | 6 | .. | .. | .. | .. | .. | .. | .. | .. |
| 3 | 8 | 7 | 7 | 6 | .. | .. | .. | .. | .. | .. | .. |
| 4 | 8 | 8 | 7 | 7 | 6 | .. | .. | .. | .. | .. | .. |
| 5 | 9 | 8 | 8 | 7 | 7 | 6 | .. | .. | .. | .. | .. |
| 6 | 9 | 9 | 8 | 8 | 7 | 7 | 6 | .. | .. | .. | .. |
| 7 | 10 | 9 | 9 | 8 | 8 | 7 | 7 | 6 | .. | .. | .. |
| 8 | 10 | 10 | 9 | 9 | 8 | 8 | 7 | 7 | 6 | .. | .. |
| 9 | 12 | 10 | 10 | 9 | 9 | 8 | 8 | 7 | 7 | 6 | .. |
| 10 | 12 | 12 | 10 | 10 | 9 | 9 | 8 | 8 | 7 | 7 | 6 |

# CHAPTER V

# THE STRUCTURAL ELEMENTS

## ARTICLE 23. INTRODUCTION AND GENERAL DISCUSSION

The structure of all buildings is made up of various combinations and forms of walls, columns, ties, beams, trusses, and arches. These may be classed as the *structural elements.*

Walls are usually constructed of some form of masonry as described in Chapter IV, or of wood as in frame construction, or of corrugated steel sheets as used on some types of mill buildings.

Columns and beams may be constructed of timber, steel, or reinforced concrete. Cast iron was extensively used at one time for columns and for short beams such as lintels, but steel and reinforced concrete have largely taken its place. Wrought iron has been entirely replaced by steel as a structural material.

Trusses are usually constructed of steel but timber is used quite extensively and reinforced concrete occasionally. Reinforced concrete is not usually considered an appropriate material for truss construction although there are many examples of its successful use where local conditions have led to its selection.

Arches of long span are usually constructed of steel and reinforced concrete but excellent results may be secured with timber when it seems desirable to use that material. Arches over openings in walls are usually constructed of brick or stone as described in Articles 17, 18, and 19.

The assembling of the various structural elements so that each may perform its functions is known as *framing.* One classification of buildings is on the basis of the function of the walls. If the walls carry their share of the dead, live and other loads in addition to keeping out the weather, etc., the building is classed as *wall-bearing construction;* but if the loads, including the weight of the walls, are carried by the structural frame consisting of columns, beams, trusses and arches, the building is classed as *skeleton construction* as explained in Article 2. This term is usually used only for buildings of the office building type and not for the mill building type.

**Frame construction** with structural elements consisting of light wood joist and studs is extensively used in dwelling house construction but is not used for larger buildings.

**Ordinary construction** is similar to frame construction but has exterior walls of masonry. It is extensively used for dwelling house construction but its chief field is for apartment houses, stores, and industrial buildings of various types which require a better class of construction than frame construction but which do not need to be slow-burning or fireproof.

**Slow-burning construction** consisting of heavy timber beams, girders, columns, floors and roofs with masonry walls is extensively used for manufacturing plants and industrial buildings requiring a substantial form of construction which will offer considerable resistance to fire.

**Steel construction** consisting of steel beams, girders, columns and trusses supporting floors and roofs of light joist construction, of heavy timber construction, or of fireproof construction is extensively used on all classes of buildings except dwelling houses. The exterior walls may be bearing walls for the lower buildings but for buildings of more than 3 or 4 stories skeleton construction is used. In the better class of buildings fire-resistive construction is used throughout. For buildings up to 15 or 20 stories high, steel and reinforced-concrete construction are on a competitive basis but for higher buildings steel construction is without a rival. Great speed is possible with steel construction. In some cases, the structural frame and floor slabs have been constructed at the rate of a story a day after the foundations are in place.

**Reinforced-concrete construction** may be used for nearly all classes of buildings where good construction is essential. Dwelling houses are rarely of this type but apartment houses, hotels, office buildings, school houses, warehouses, and industrial buildings are commonly built of reinforced concrete. In buildings with a steel framework the floors and roofs are often of reinforced concrete. For tall buildings steel construction has the advantage on account of the smaller size of the columns for the lower floors. This advantage has resulted in the limiting of concrete buildings to 15 or 20 stories. In some cases the columns of the lower stories are made of steel and those above of concrete. For buildings 3 or 4 stories in height exterior bearing walls may be used but above that height skeleton construction is adopted. Even for the lower buildings, skeleton construction may be used on account of the greater speed of construction which is possible with this type. When bearing walls are used each floor must wait until the bearing wall can be built up to carry it whereas with skeleton construction the structural frame and floor slabs may be constructed as rapidly as a story every two days after the foundations are in place.

## ARTICLE 24. COLUMNS AND OTHER COMPRESSION MEMBERS

Forces which tend to shorten or compress a member are called *compressive forces* and the stresses set up in a member by these forces are called *compressive stresses*. *Bending* or *flexural stresses* are set up in a member when it is bent.

The vertical members of a structural frame are called columns. They are called upon to transfer the floor and roof loads to the foundations. Such loads cause stresses in the columns which are chiefly compressive but on account of eccentric loads, rigidity of joints, and wind loads, columns are also subjected to bending stresses which may be of considerable magnitude.

**Classes of Columns.** — Columns may be divided into three general classes according to the ratio of the longitudinal dimension to the lateral dimension.

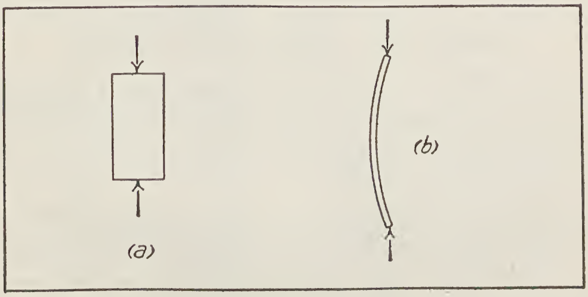



FIG. 53

If the length of a column is relatively small when compared with its width, as shown in Fig. 53*a*, the column does not tend to bend to any extent, when carrying a load, and if the load is applied so that its center of gravity is on the axis of the column the stresses will be uniformly distributed over each cross-section of the column. If the length of a column is great when compared with its width, the column will tend to fail by bending or buckling as shown in Fig. 53*b* when carrying a load, the magnitude of the compressive stress being small. A third class would include those columns intermediate in ratio of length to width to the classes just mentioned; such columns tend to fail by a combination of direct stress and bending or buckling. Reinforced-concrete columns are usually of the first class; timber and steel columns may be in either the first or third class. Columns of the second class are not used to any extent.

**Other Terms Used.** — Columns are often called *posts*, especially when made of timber. Truss members carrying compressive stresses are called

*struts*, but their action is the same as that of columns. In general, members which carry compressive stresses are called columns, posts, struts, or props.

The light, closely spaced, vertical, compressive members used in frame construction are called *studs*. Relatively slender blocks or prisms of masonry carrying compressive stresses are called *piers*. Stone or brick columns are sometimes called *pillars* but this is not a technical term. The term pier has about the same meaning as pillar and is more commonly used. In England, the term *stanchion* is used in place of the term column as used in this country. Light steel columns of the H-section type have been put on the market by the Bethlehem Steel Company classed as stanchions.

**Materials.** — Columns are usually made of timber, steel, reinforced concrete or cast iron, but stone columns are frequently used for ornamental purposes.

## ARTICLE 25. BEAMS AND GIRDERS

A beam may be defined as a member supported at one or more points along its length and designed to carry loads acting perpendicular to its length, the reactions at the supports being parallel to the direction of the loads as shown in Fig. 54*a*.

If the line of action of the loads is not perpendicular to the length of the beam, these loads may be resolved into components acting perpendicular to the length of the beam and components acting parallel to the length of the beam as shown in Fig. 54*b*. In carrying the transverse components the beam is performing its primary function, while in carrying the components parallel to its length it is acting as a column.

A beam may be curved or bent as shown in Fig. 54*c* if the supports are so arranged that the reactions at the supports will be vertical for vertical loads. This may be accomplished by placing one end on rollers as shown in Fig. 54*c* or, to a certain degree, by using plates which permit sliding. If the ends are so arranged that horizontal movement is restricted as the structure deforms, the reactions will no longer be vertical and the structure will be an arch as shown in Fig. 54*d*.

**Flexural Stresses.** — There are two general classes of stresses set up in a beam by the loads, i.e., flexural or bending stresses, and shearing stresses. The material on the upper side of the beam shown in Fig. 54*a* is compressed or shortened and that on the lower side is elongated. The stresses causing the shortening are called *compressive stresses* and those causing the elongation are called *tensile stresses*. Taken together they are called *flexural stresses*. These stresses are greatest at the top and the bottom of the beam, and zero at the *neutral axis* near the center of the

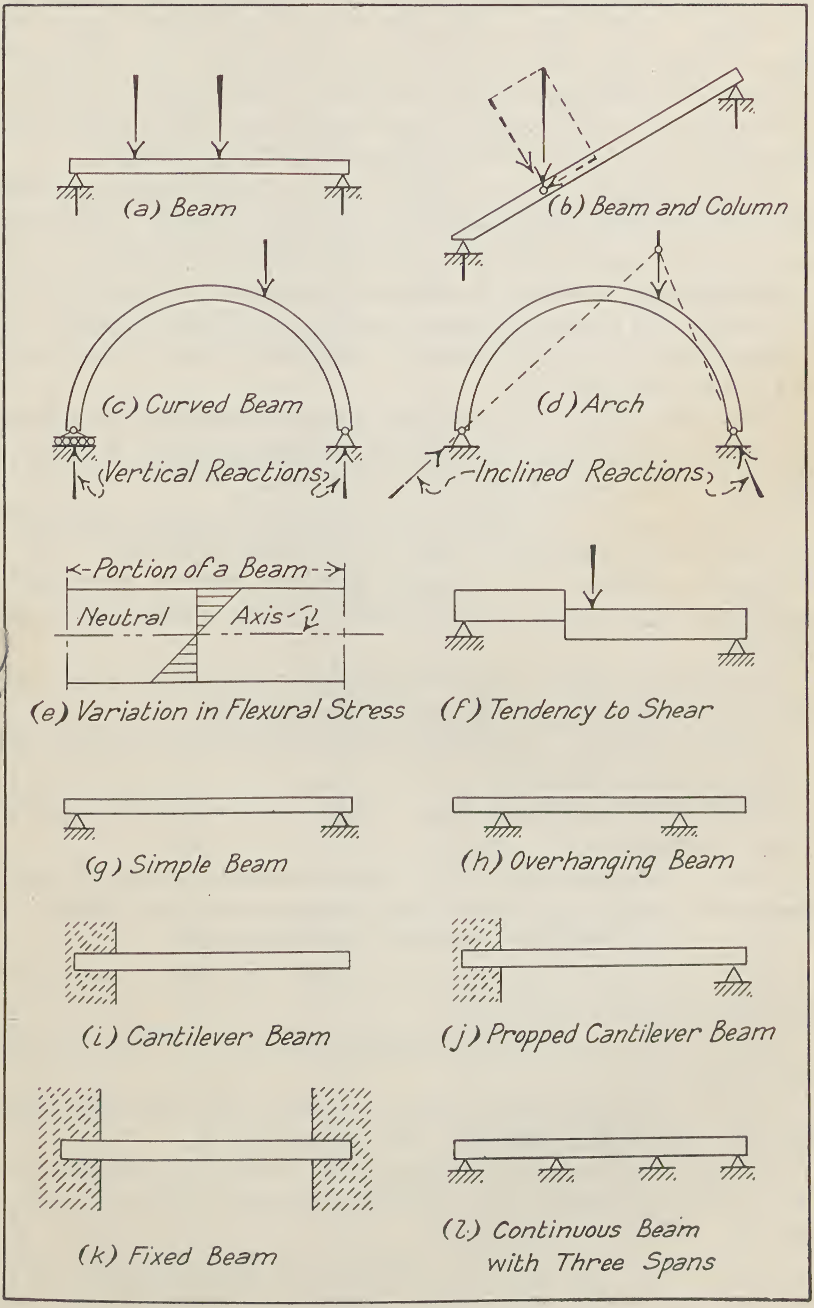



Fig. 54. Types of Beams

depth, the exact location of the neutral axis depending upon the shape of the section. For a beam composed of one material the neutral axis passes through the centroid of the transverse section. The variation of stress may be illustrated by the triangles in Fig. 54*e*, the intensity of stress usually varying directly as the distance from the neutral axis as indicated by the lengths of the horizontal lines in the triangles.

**Shearing Stresses.** — It is evident that the forces acting on a beam tend to cut it along vertical sections as shown in Fig. 54*f*. The stresses set up in the beam by this action are called *shearing stresses.*

**Classification According to Method of Support.** — Beams may be divided into the following classes according to method of support:

*Simple beam.* — A simple beam is supported at two points near its ends as shown in Fig. 54*g*.

*Overhanging beam.* — An overhanging beam is supported at two points but projects beyond or overhangs one or both supports as shown in Fig. 54*h*. It is a special case of the simple beam.

*Cantilever beam.* — A cantilever beam is supported at one end only but it is rigidly held in position at that end as shown in Fig. 54*i*.

*Propped cantilever.* — A propped cantilever beam is supported at two points and is rigidly held in position at one of them as shown in Fig. 54*j*.

*Fixed beam.* — A fixed beam is supported at two points and is rigidly held in position at both points as shown in Fig. 54*k*.

*Continuous beam.* — A continuous beam is supported at three or more points as shown in Fig. 54*l*.

**Classification According to Use.** — Beams may be classified according to use as follows:

*Beam.* — When any distinction is made between beams and girders the beam is the smaller member and may be supported by the girder.

*Girder.* — See discussion under the heading of *Beam.*

*Lintel.* — A beam supporting the masonry and other loads over an opening in a wall. See Fig. 145.

*Joists.* — Closely spaced beams supporting a floor or ceiling. See Figs. 81 and 82.

*Rafters.* — Closely spaced beams supporting the roof and running parallel to the slope of the roof. See Figs. 81 and 82.

*Hip rafter.* — The member running along the hip of a framed hip roof and having the ends of the jack rafters fastened to it. See Figs. 80 and 133.

*Valley rafter.* — The member running along the valley of a framed roof and having the ends of the jack rafters fastened to it. See Fig. 133.

*Jack rafter.* — Any short rafter, but usually a rafter running between the wall plate and the hip rafter and called a *hip jack* or between the valley rafter and the ridge and called a *valley jack*. See Fig. 133.

*Purlin.* — A beam resting on the top chords of roof trusses or girders and supporting the rafters or other roof construction. See Fig. 133.

*Girt.* — A beam placed horizontally on the sides of a building and fastened to the columns. See Fig 104.

*Header.* — A beam which carries the ends of beams which are cut off in framing around an opening as shown in Fig. 55.

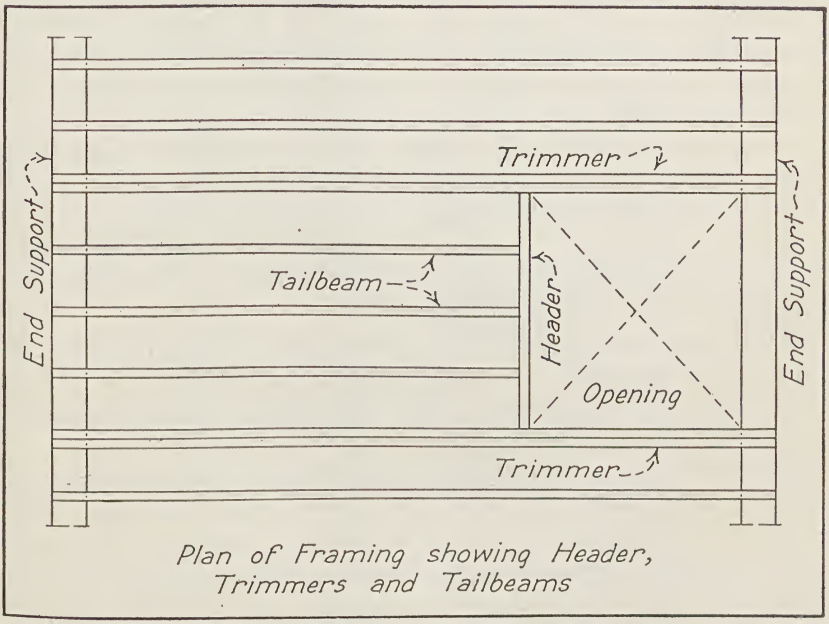



FIG. 55. Headers, Trimmers and Tail Beams

*Tail beam.* — A beam which frames into a header instead of spanning the entire distance between supports. See Fig. 55.

*Trimmer.* — A beam at the side of an opening and carrying one end of a header as shown in Fig. 55.

*Collar beam.* — A horizontal member running between two rafters on opposite sides of a framed roof and usually, but not necessarily, located at some distance above the wall plates. See Fig. 82. A collar beam does not necessarily act as a beam. It may act as a tie if the rafters are not so anchored as to prevent the spreading of the lower ends but if they are securely held at that point the collar beam acts as a strut which reduces the deflection in the rafters.

**Materials.** — Beams may be constructed of timber, steel, or reinforced concrete, as described in the following articles. Cast iron was quite extensively used a number of years ago and stone is occasionally used for lintels but, due to their low flexural strength, stone lintels are usually supported by steel lintels which do not show on the face of a building.

## ARTICLE 26. TRUSSES

A *truss* is a framed structure consisting of a group of triangles arranged in a single plane in such a manner that loads applied at the points of intersection of the members will cause only *direct stresses* (tension or compression) in the members. The framework shown in Fig. 56*a* will illustrate the essential features of a truss, although a truss of this type is of no practical use.

To be classed as a truss the ends of a framework must be supported in such a manner that the reactions at the supports are vertical for vertical loads. This result is accomplished by arranging one end so that horizontal movement may take place by sliding or rolling on the bearing plate as shown in Fig. 56*b* when loads are applied, or when changes of length due to temperature changes occur.

If the ends are so arranged that horizontal movement is restricted the reactions will be inclined and the framework will act as an *arch* as shown in Fig. 56*c*. It is not customary to provide sliding or rolling bearings for trusses whose span does not exceed 40 or 50 ft.

**Parts of a Truss.** — The points of intersection of the members of a truss are called *joints* or, in some cases, *panel points*. The upper line of members forms the *upper* or *top chord* and the lower line, the *lower* or *bottom chord*. The members connecting the joints on the upper chord to those on the lower chord are the *web members*. See Fig. 56*a*. Members carrying compressive stresses are *struts* and those carrying tensile stresses are *ties*. The terms *end post*, *vertical post*, *hip vertical* and *panel* apply to special forms of trusses and will be defined later. See Fig. 56*k*. The distance center to center of supports is called the *span*.

**Materials.** — Trusses may be built wholly of timber, of timber and steel rods combined, or of rolled steel sections. Concrete is used to a limited extent but is not a suitable material for trusses. Cast iron and wrought iron have been used in the past but these materials are not used at the present time.

**Types of Trusses.** — Considering that a truss is composed of a group of triangles it is evidently possible to arrange innumerable types but certain types have proved to be more satisfactory than others and each of these types has its special uses. The various types of trusses used in building

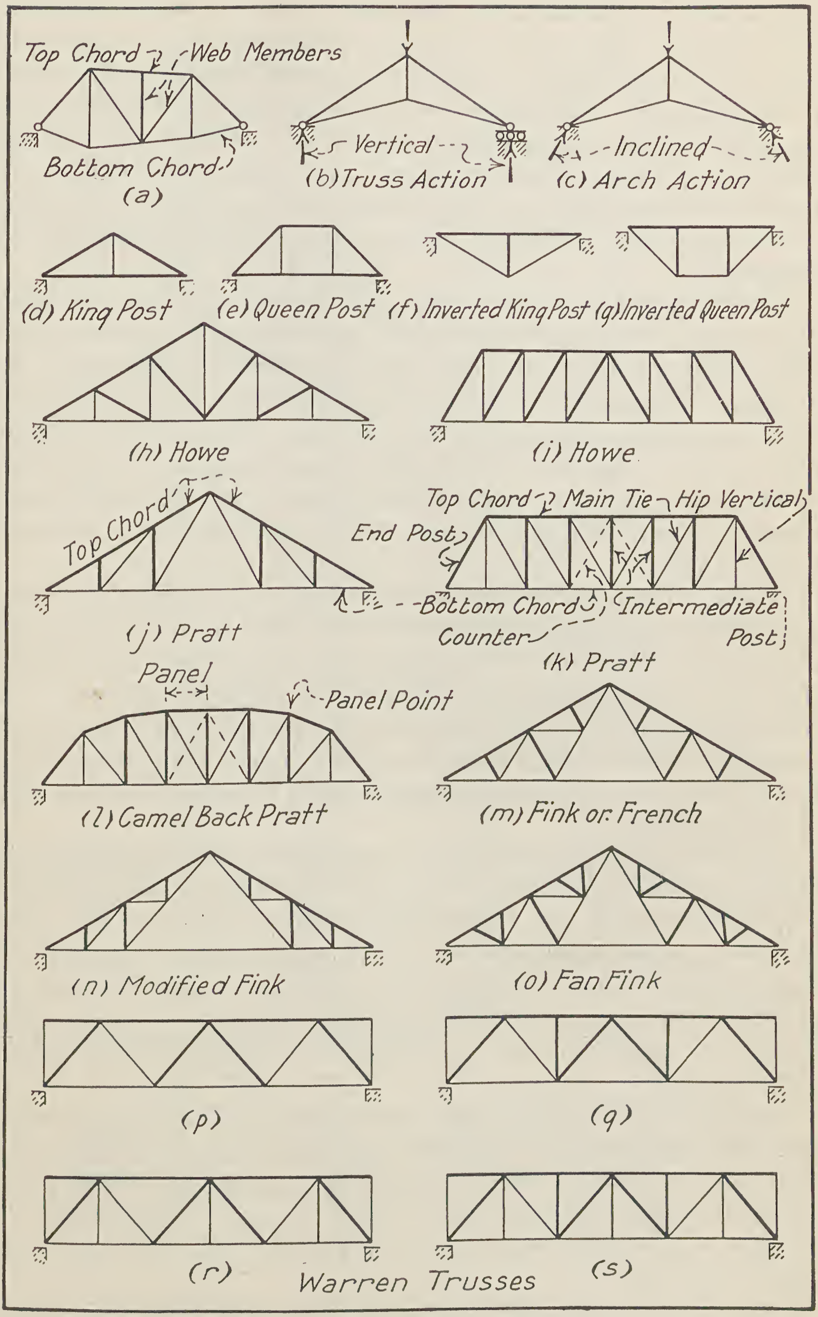



Fig. 56. Types of Trusses

construction are illustrated by line diagrams in Fig. 56*d* to Fig. 57*n*. The members indicated by heavy lines normally carry compressive stresses and those indicated by light lines normally carry tensile stresses, for vertical loads. The types shown with parallel chords may have their top chords made sloping slightly in one or two directions, for roof drainage, without changing the type. The number of subdivisions or panels will depend upon the length of span and the type of construction.

The more common forms of trusses will be discussed in the following paragraphs.

The *king-post truss* shown in Fig. 56*d*, the *queen-post truss* shown in Fig. 56*e* and the *inverted king-post* and *queen-post trusses* shown in Figs. 56*f* and 56*g* are all used for short spans in connection with timber construction. The members indicated by heavy lines are made of timber and those by light lines are usually steel rods. The inverted king-post and queen-post trusses are often called *trussed beams* and are described in Article 30. The lower chords of the trusses in Figs. 56*d* and 56*e* carry tensile stresses but are usually made of timber and therefore are indicated by heavy lines.

The *Howe truss* may be constructed with inclined top chords as shown in Fig. 56*h* or with parallel chords as shown in Fig. 56*i*. Howe trusses are always constructed with the members indicated by heavy lines made of timber and those indicated by the light lines made of steel rods. The truss with sloping chords is commonly used for pitched roofs whereas the truss with parallel chords may be used to support flat roofs or floors. Howe trusses may be divided into any number of panels to suit any span or purlin spacing.

The *Pratt truss* may be constructed with inclined top chords as shown in Fig. 56*j* with parallel chords as shown in Fig. 56*k* or with broken upper chord as shown in Fig. 56*l* forming a *camel-back Pratt truss*. Pratt trusses are usually constructed entirely of steel sections. The truss with sloping chords is used for supporting sloping roofs and the type with parallel chords may be used for supporting flat roofs or floors. Pratt trusses may be divided into any number of panels to suit any span or purlin spacing.

The *Fink truss* is always constructed with inclined chords as shown in Fig. 56*m*, and all of the members are made of steel sections. Fink trusses are very widely used in supporting sloping roofs. They may be divided into any number of panels to suit any span or purlin spacing. A modified form of Fink truss is shown in Fig. 56*n* and a *fan Fink* or *fan truss* in Fig. 56*o*.

The *Warren truss* is always constructed with parallel chords as shown in Fig. 56*p*. Vertical members may be provided to reduce the distance

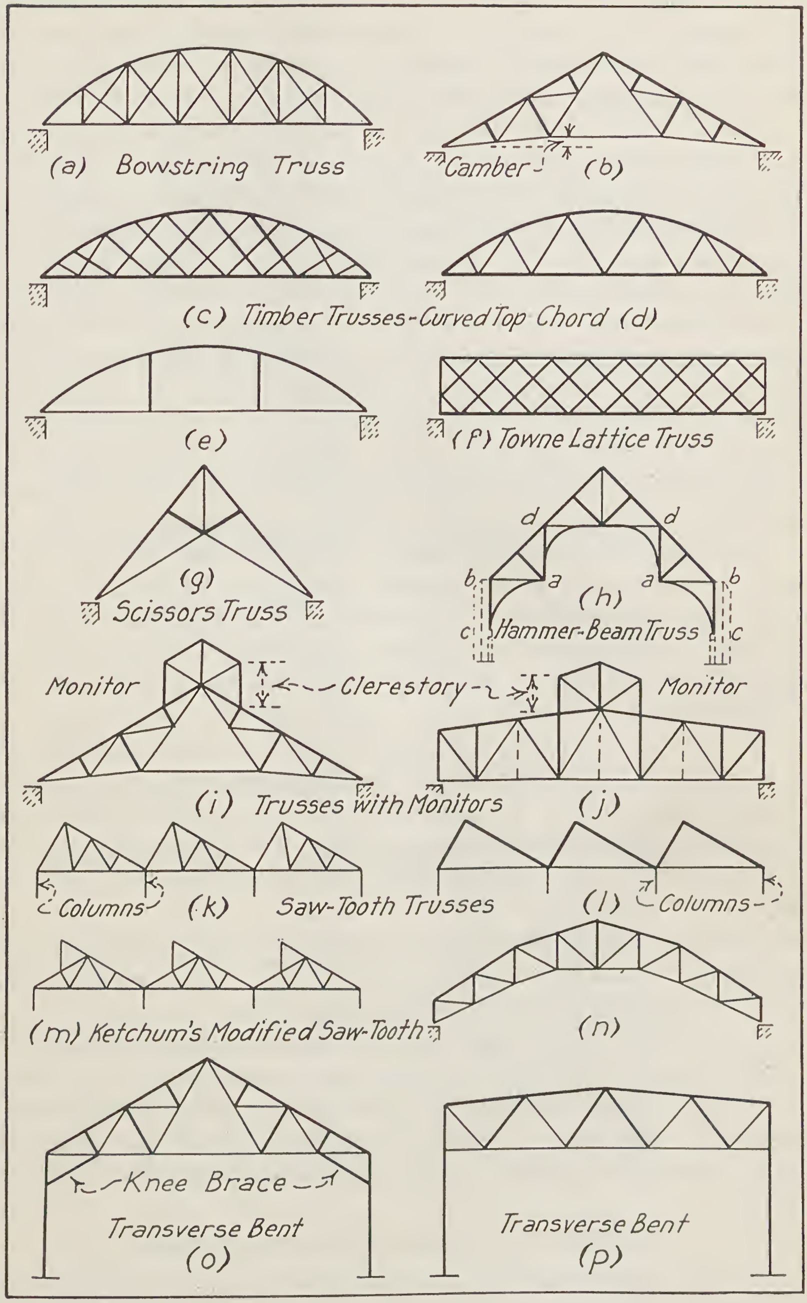



Fig. 57. Types of Trusses

between joints on the upper chord as shown in Fig. 56*q*, on the lower chord as shown in Fig. 56*r* or on both chords as shown in Fig. 56*s*. The Warren truss is very widely used for supporting floors or flat roofs. The *bowstring truss* shown in Fig. 57*a* is used very little at the present time.

A truss is said to be *cambered* when the bottom chord is raised at the center as in the cambered Fink truss shown in Fig. 57*b*. Camber improves the appearance of a truss and avoids the illusion of sagging.

Various special forms of timber roof trusses are shown in Fig. 57*c* to *h*. The trusses shown in Figs. 57*c* and 57*d* have curved upper chords, the various members being built up of one-inch or two-inch timbers. A curved trussed beam is shown in Fig. 57*e*. This beam is built up of light timbers and steel rods. A *scissors truss* is shown in Fig. 57*g*, a *hammer-beam truss* in Fig. 57*h*, and a *Towne lattice truss* in Fig. 57*f*. In the hammer-beam truss shown in Fig. 57*h* the parts of the truss marked *a b c* act as brackets to reduce the span to *d d*. These brackets must be securely fastened to the wall along the vertical member *b c* and the wall must be capable of withstanding the outward thrust produced at the point *c*.

Other special forms of roof trusses are shown in Fig. 57*i* to *n*. *Monitors* are placed on top of roof trusses as shown in Fig. 57*i* and *j* to give better light and ventilation, the vertical face of a monitor, called the *clerestory*, being provided with glass in sash which will open to provide light and ventilation, or with *louvres* for ventilation only. See also Fig. 132*d* and *e*.

The *saw-tooth trusses* shown in Fig. 57*k* and *l* are used to provide light and ventilation, the steeper face of the roof being covered with glass so arranged that a part of the sash will open. This face is usually turned toward the north to secure a uniform light. The type shown in Fig. 57*k* is constructed of steel and that in Fig. 57*l* is constructed of timber and steel rods. See also Fig. 132*b*.

Another form of saw-tooth truss is shown in Fig. 57*m*. In this type the vertical face is provided with top-hung sash. This type is always constructed of steel sections. See also Fig. 132*c*.

A camel-back Pratt truss with cambered lower chord is shown in Fig. 57*n*.

Steel or timber roof trusses may be secured to columns in such a way as to give lateral rigidity as shown in Fig. 57*o* and *p*. Such combinations of trusses and columns are called *transverse bents*. In the transverse bent shown in Fig. 57*o* the braces between the truss and columns are called *knee braces*.

## ARTICLE 27. ARCHES AND RIGID FRAMES

The use of brick and stone arches in building construction has been discussed in Chapter IV. They have a structural function but their design is determined largely by appearance.

Arches the primary function of which is structural are constructed of timber, steel, and reinforced concrete. They are used chiefly for the support of roofs covering large areas such as required in auditoriums, armories, exhibition buildings, field houses for athletics, gymnasiums, dance halls, hangars, and garages.

Arches may have solid arch rings which are subjected to compressive and flexural stresses or they may be built up of triangular elements in the same manner as trusses, in which case they are called *framed arches.*

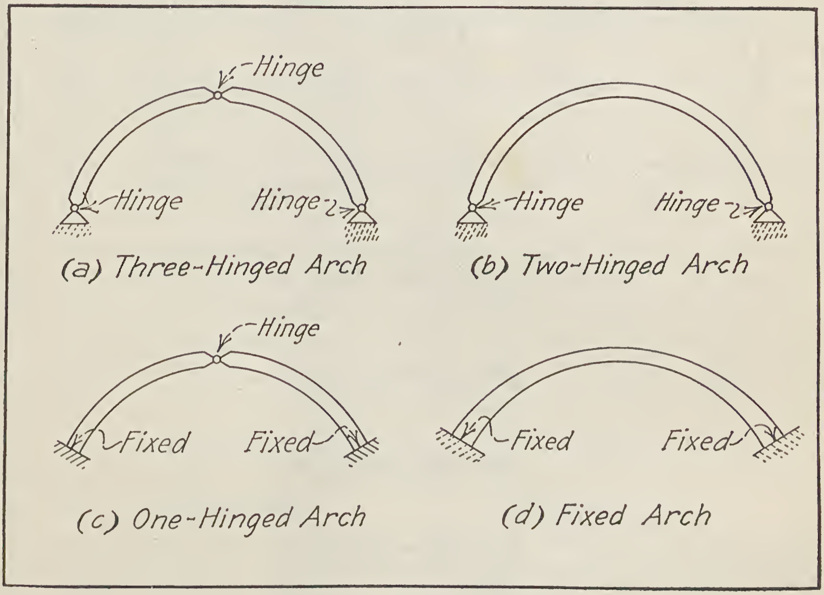



FIG. 58. Types of Arches

The members of framed arches carry tensile or compressive stresses but not bending stresses. Reinforced-concrete arches are always of the type with the solid arch ring and steel arches are usually framed.

Arches may be constructed with the ends of the arch ring securely anchored to the abutments, or hinges which permit rotation may be introduced at these points or at the crown. In the *three-hinged arch* there is a hinge at each abutment and one at the crown, as shown in Fig. 58*a*; in the *two-hinged arch* there is a hinge at each abutment as shown in Fig. 58*b*; in the *one-hinged arch* there is a hinge at the crown but the ends of the arch ring are securely fixed at the abutments as shown in Fig. 58*c*; and in the *no-hinged* or *fixed arch* no hinges are provided and the ends of the arch ring are rigidly anchored to the abutments as shown in Fig. 58*d*. Steel and timber arches are usually of the three-hinged or

two-hinged type. Reinforced-concrete arches may be of the three-hinged, two-hinged, or fixed types. The one-hinged arch is rarely used.

*Rigid frames* of reinforced concrete are coming into use. They may be of simple form as shown in Fig. 59*a* or they may consist of several units as shown in Fig. 59*b* and *c*. The wind bents of tall steel buildings and the

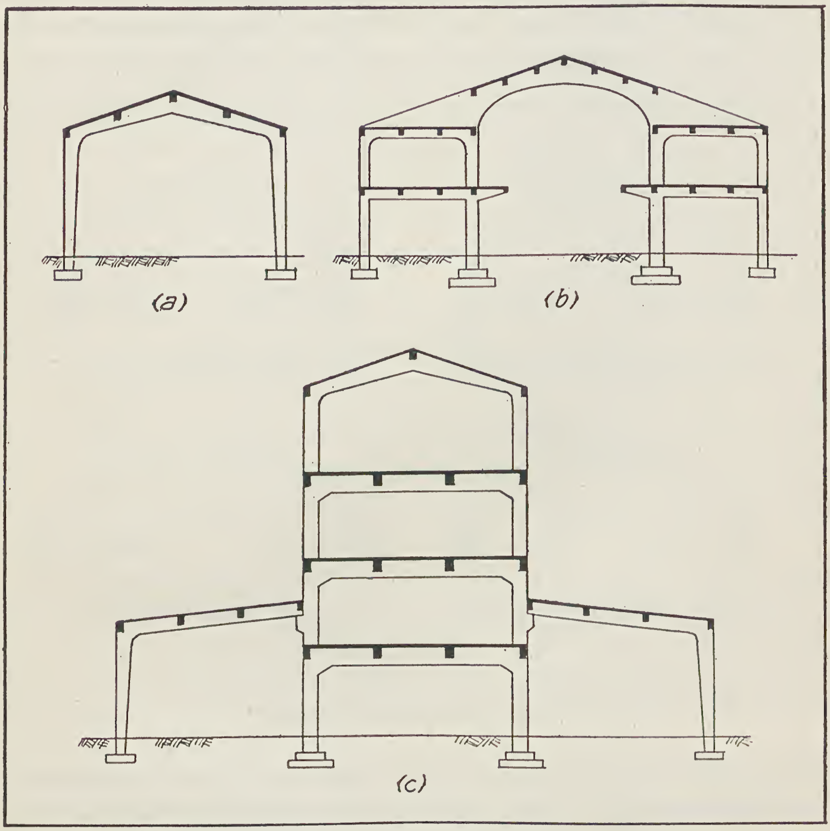



FIG. 59. Examples of Reinforced-concrete Rigid Frames

unit formed by the columns and girders in a reinforced-concrete frame are complex rigid frames although they are not usually classed as such. The most common type of rigid frame consists of a roof girder or arch rigidly connected to the columns at its ends so that the three elements act together in resisting vertical and lateral loads, the horizontal reaction of the arch and the deflection of the girder causing bending in the columns.

## CHAPTER VI

# FRAME, ORDINARY, AND SLOW-BURNING CONSTRUCTION

### ARTICLE 28. FRAME WALLS AND PARTITIONS

**Wood-stud Construction.** — Walls and partitions in which the structural elements are wood are classed as frame construction. These structural elements are usually closely-spaced slender vertical members called *studs* arranged in a row, with their lower ends bearing on a long horizontal member called a *bottom plate* or *sole plate,* and with their tops capped with another plate called a *top plate.* Short members called *bridging* or *fire-stopping,* placed horizontally, or approximately so, are cut in between the studs at their mid-height to give them lateral support and to restrict the spread of fire upward on the inside of the partition. The framing for walls and partitions of this type is shown in Fig. 60*a*.

The bearing strength of stud walls and partitions is determined by the strength of the studs acting as struts or columns. The spacing of studs is always 12 in. or 16 in. so that they will support, without waste, wood lath with the standard length of 4 ft. A 24-in. spacing is too great for ordinary wood lath. Metal lath lengths are made to conform to the 12 and 16-in. spacing of studs.

The minimum size of stud which should be used is 2 × 4 in. but the loads may require 2 × 6-in. or 2 × 8-in. studs for some bearing walls and partitions. Studs 3 in. thick are sometimes used.

The Uniform Building Code adopted by the Pacific Coast Building Officials Conference contains the following requirements:

Stud partitions shall be provided with soles or plates with dimensions not less than the studs where the partition studs do not rest on walls, girder beams, or do not pass through the floor to the top plate of the partition below.

In bearing partitions the top plates shall be doubled and lapped at each intersection. Joints in the upper and lower members of the top plate shall be staggered not less than 2 ft.

Studs in bearing partitions and walls shall not be less than 2 in. by 4 in. in size. Where a bearing partition supports more than the weight of the roof and one floor the studs shall be not less than 2 in. by 6 in. or 3 in. by 4 in. except that underpinning may be of the same size as the studs immediately above when such underpinning is not more than 4 ft. in height.

Where studs pass through from floor to floor they shall be fire-stopped at point of passage through floors. (See Fig. 60*b*.)

Angles at corners where stud walls or partitions meet shall be framed solid so that no lath can extend from one room to another. All exterior and main cross stud partitions shall be effectively and thoroughly angle braced. (See Fig. 60*c*.)

Openings in stud partitions and walls shall be framed around with double studs at each side and double headers across the top resting on the short stud at each

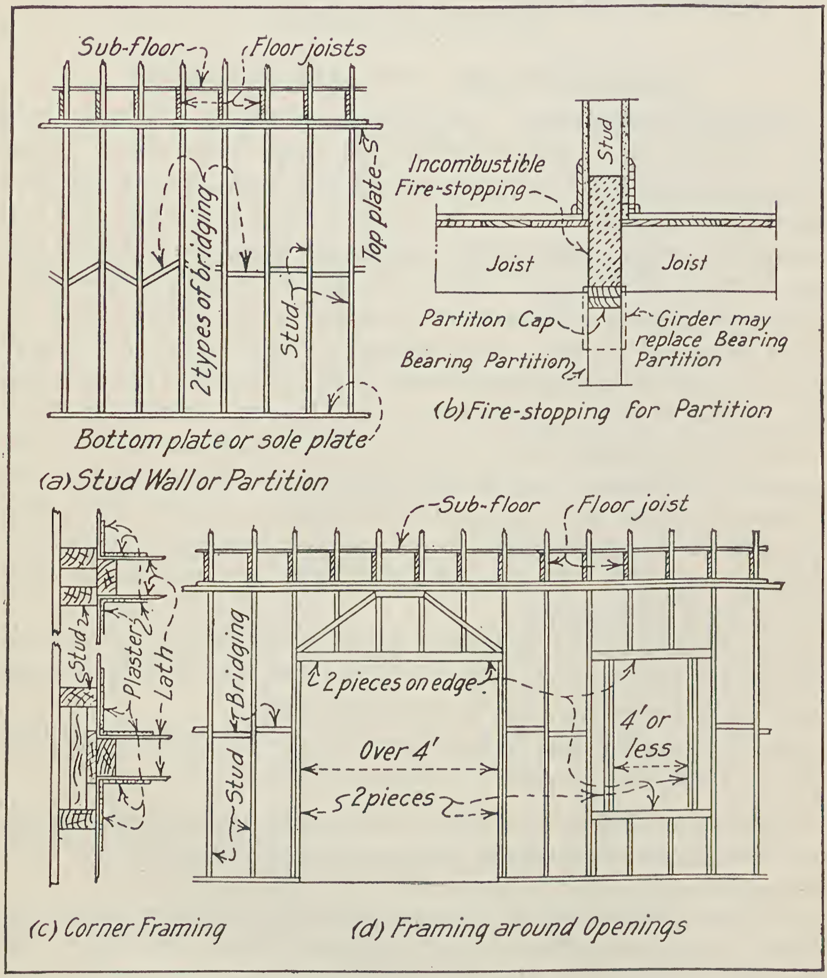



Fig. 60. Frame Walls and Partitions

end. The double header shall be placed on edge and shall be trussed above for all openings over 4 ft. in width or where more than two studs are cut away. (See Fig. 60*d*.)

Where wood partitions and masonry walls join, bolts 10 in. long with 2-in. by 5-in. by ¼-in. iron washers shall be built into the masonry wall opposite each line

of fire-stopping (bridging) and near the top plate or ribbon in each partition. The projecting end of the bolt shall pierce the partition and be securely fastened thereto.

All stud walls or partitions shall have a continuous row of bridging or fire-stopping which shall form a complete and effective separation the entire width of partitions at that point, placed in such a manner that there shall be no concealed air spaces greater than 7 ft. in any dimension. Fire-stops shall be the full width of the studding and sufficiently stiff to act as lateral bracing for the individual units. See partition framing in Fig. 60*a*.

A partition which is not supported by a wall or partition below should be supported by girders or double joists if it runs parallel to the joists or by a bottom or sole plate if it is placed at an angle to the joists of the floor below.

When the studs of bearing partitions are placed directly below each joist it is desirable but not essential that a double top plate be used as required in the regulations which have just been quoted. Non-bearing partitions do not require double plates but they are desirable here also.

It is very common practice in framing partitions to place the lower ends of studs on a sole plate placed on top of the sub-floor instead of running the studs through the floor to the top plate of the studs for the story below.

This practice is very objectionable unless the outside wall is framed in the same way for the side shrinkage of the floor joists, the sub-floor and the plates at each floor causes considerable settlement and if there is not a corresponding shrinkage in the outside walls the unequal settlement will cause bad plaster cracks in the partitions which have one end at an outside wall. If the outside walls are of masonry this shrinkage will, of course, not be present. In the *balloon frame*, Fig. 61*a*, the outside studs are continuous for two stories so the only side shrinkage is in the sill which rests on the masonry wall. The same is true of the *braced frame*, Fig. 61*b*, except for the side shrinkage of the girt on which the joists rest. A type of construction known as the *platform frame* or *Western frame* uses studs which extend through one story in the outside walls as well as in the partitions as shown in Fig. 60*c*. In both cases the studs are placed on a plate resting on the sub-floor so the shrinkage is equalized and the plaster cracks are avoided.

In Figs. 60*a* and *b* the first-floor joists are not placed on top of the girder in the basement but rest on strips nailed to the sides of the girder and along the bottom edge. This detail reduces the settlement due to side shrinkage. The shrinkage may be avoided entirely by using a steel I-beam in place of the timber girder. These strips are called *ledger* strips.

Side shrinkage may be ½ in. or more in 12 in. and may amount to as much as 2 in. in a poorly constructed two-story building. End shrinkage is much smaller than side shrinkage and is not a serious factor. Seasoned lumber shrinks much less than green lumber and quarter-sawed lumber much less than flat-sawed. Swelling due to the absorption of moisture

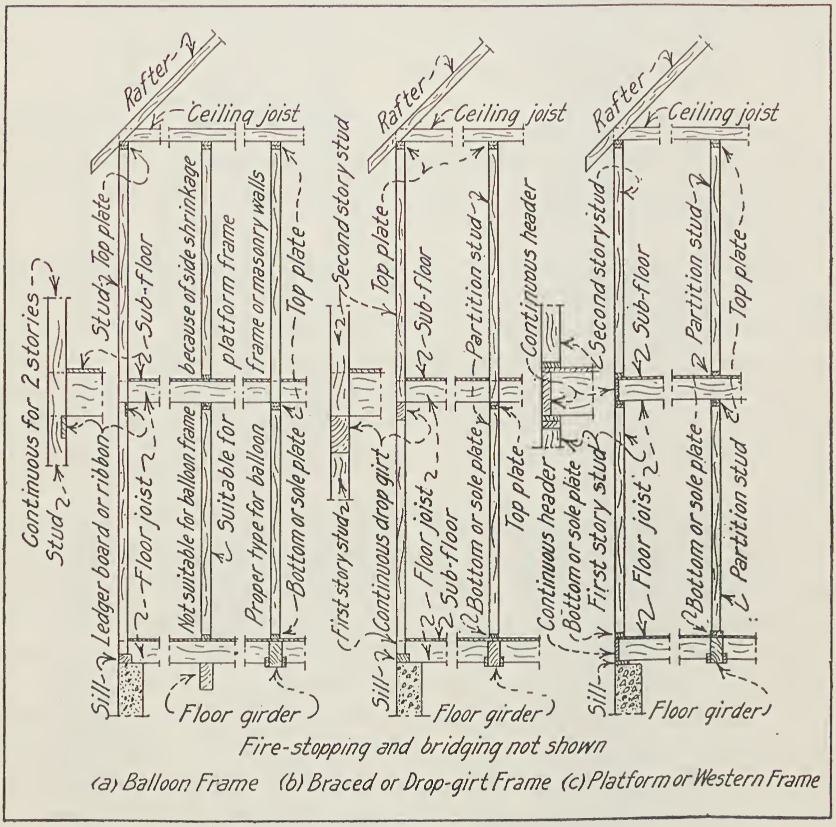



Fig. 61. Frame Construction

has the opposite effect from that of shrinkage. As atmospheric conditions change a timber frame is constantly moving due to shrinkage and swelling. It is important to reduce these factors to a minimum.

**Sheathing.** — For most forms of covering which are applied to the exterior of wood-stud walls it is first necessary to cover the entire surface with sheathing to increase the rigidity and heat-insulating properties of the wall.

Wood sheathing may be plain boards, matched boards, or ship-lap and should be at least 1 × 6 in. If laid horizontally it is less apt to result in

stucco cracks than if laid diagonally but diagonal sheathing is much more effective in bracing the frame. When sheathing is thoroughly dry it can be put on horizontally and a rigid wall obtained but in most cases diagonal braces should be provided at the corners. These braces may consist of 2 × 4-in. pieces cut in between the studs or of continuous 1 × 6-in. boards let into the studs. If metal lath is back-plastered the sheathing may be omitted.

Various forms of fiber boards and other sheathing materials are used in place of wood sheathing. Some of these serve also as a base for the stucco and are described in Article 79.

**Exterior Surfaces.** — The exterior face of wood-stud walls may be covered with boards of special design, called *siding*, placed horizontally

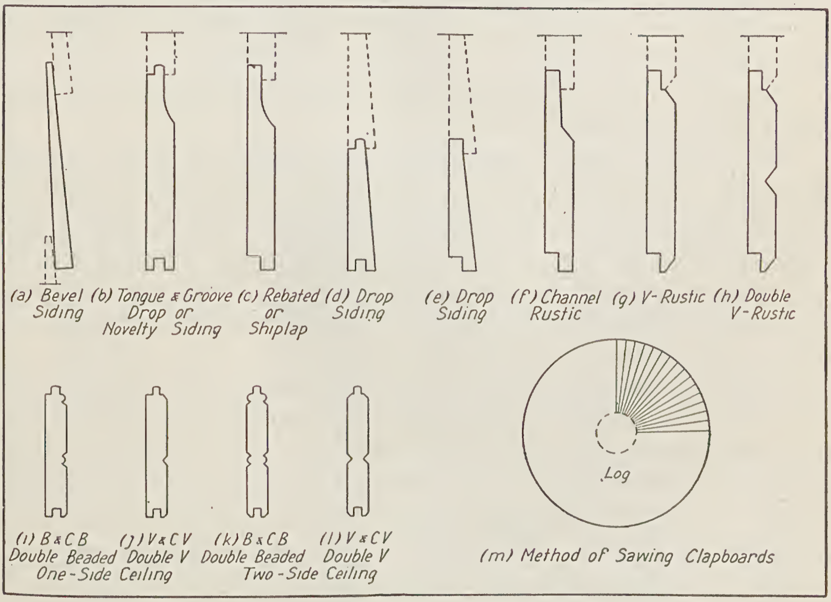



FIG. 62. Types of Siding and Ceiling

and nailed to the studs with or without an intervening layer of wood sheathing or fiber board. A heavy specially treated paper such as rosin-sized building paper, tar paper, or sheathing paper may be placed under the siding to make the surface more weather-tight. There are two general types of siding, i.e., *bevel siding* which is tapered or beveled so that it is thinner on the upper edge than on the lower edge as shown in Fig. 62*a*, and which is lapped in laying, and *drop* or *novelty siding* which has a tongue-and-groove joint or a *rebated* or *ship-lap joint* as shown in the various designs of Fig. 62*b* to *h*, some forms of which will give the same

effect as bevel siding. Many other designs are manufactured. The common widths are 6 in. and 8 in. (nominal) and the thicknesses $\frac{9}{16}$ in. and $\frac{3}{4}$ in. (actual) but other widths and thicknesses are available.

*Rustic sidings* and *colonial sidings* are special forms of drop siding. Bevel siding is sometimes called *weather-boarding.*

Siding is made of Douglas fir, white and yellow pine, spruce, hemlock, redwood, cedar, and cypress.

*Clapboards* are used to a limited extent in the same manner as siding. They have about the same cross-section as bevel siding but taper to almost a feather edge. All of the boards are quarter-sawed for they are made by sawing a log radially into wedge-shaped boards as shown in Fig. 62*m.* Due to the taper of logs, boards of uniform width cannot be made very long without considerable waste. The usual length is 4 ft. and the width 6 in. or 8 in. They are lapped in laying, with 4 or 5 in. exposed or "to the weather."

The use of siding without sheathing is illustrated in Fig. 63*a* and with sheathing in Fig. 63*b*.

Wood shingles may be used in the same manner as siding or wood sheathing as shown in Fig. 63*c*. They may be placed with more of the shingle exposed or "to the weather" than when used on roofs. Split shingles, called *shakes,* are used in the same manner as ordinary shingles but since their length may be as great as 3 ft. they are laid with a considerable length to the weather. For a more detailed discussion of shingles and shakes see Article 57.

Stucco surfaces are commonly used on the exterior of wood-stud walls. Exterior surfaces should probably be either portland cement stucco or magnesite stucco although lime stucco is also used. Portland cement stucco should not be used on wood lath and magnesite stucco should be used only on wood or galvanized metal lath for it may eat away the unprotected metal lath. The various kinds of plaster and stucco and the methods of applying them are described in Article 80. If wood lath are used, horizontal or diagonal wood sheathing should be nailed to the outside of the studs. The wood lath are held away from the sheathing by wood *furring strips* placed vertically and 16 in. apart as shown in Fig. 63*e* to enable the stucco to get a grip on the lath. The wall may be made tighter by using an asphalt-saturated felt paper between the sheathing and the furring strips. Unless the coating of stucco is watertight, rain water will swell the lath causing the stucco to crack.

If metal lath is used, crimped metal furring strips are placed over the sheathing paper directly along the line of the studs and galvanized or painted metal lath with its long dimension horizontal is placed over the furring strips and fastened by nails or staples passing into the studs as

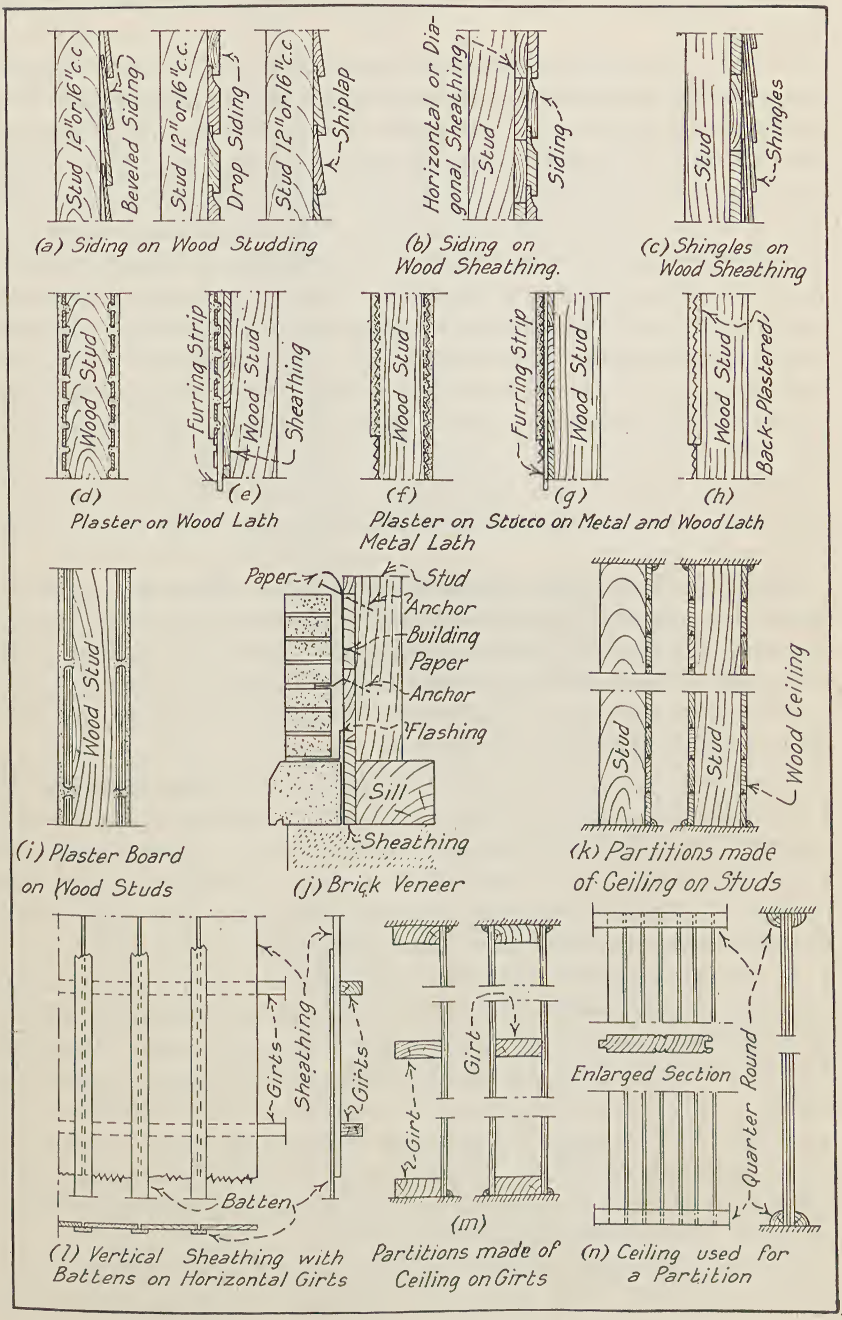



Fig. 63. Types of Frame Walls

shown in Fig. 63*g*. Some forms of metal lath are ribbed so do not require furring strips.

In another form of exterior wall construction, using metal lath, the sheathing and waterproof paper are omitted and the furring strips if used are applied directly to the wood studs. The scratch coat and brown coat are applied to the exterior and then a backing coat $\frac{5}{8}$ in. to $\frac{3}{4}$ in. thick is applied to the interior surface of the exterior lath bonding to the scratch coat which was placed from the outside. The face of this backing coat should be about $\frac{1}{4}$ in. back of the face of the studs or, in other words, the studs should be embedded in the plaster about $\frac{1}{4}$ in. It may be desirable to paint the face of the studs to prevent decay. This is known as *back-plastered construction* and is shown in Fig. 63*h*. This type of construction, using metal lath, will be sufficiently rigid if the corners of each wall are braced diagonally by 1 × 6-in. boards let into the studs on the inner side, and securely nailed to them. The studs should be braced horizontally midway in each story height with 2-in. solid bridging cut in between the studs and kept 1 in. back from the face of the studs to clear the plaster keys.

**Frame Walls Veneered With Brick or Other Masonry.** — Exterior walls with wood studs and wood sheathing, preferably matched, may be veneered with brick as shown in Fig. 63*j* or with other masonry. The veneer should rest directly on the masonry foundation of the structure and should be tied to the frame structure at intervals of not more than 16 in. vertically and 24 in. horizontally.

A satisfactory tie may be secured by driving a galvanized nail into the framework at an angle as shown in the figure and bending it into the mortar joint. This nail should be long enough to pass through the sheathing and penetrate the stud about an inch. It should be embedded in the mortar joint at least 2 in. Corrugated wall ties or wire ties nailed to the sheathing and built into the mortar joints, are also used.

An air space of about one inch should be left between the back of the brick and the sheathing and a layer of building paper should be placed over the sheathing to increase the tightness of the wall. Openings should be carefully flashed to prevent the entrance of moisture behind the facing. Adequate fire-stops should be installed at the intersection of the partitions with the walls. The frame construction should not extend below the first-floor joists. Provision must be made for any shrinkage in the timber frame or difficulties will be encountered where the window and door frames penetrate the masonry veneer.

Veneered construction resists exposure to exterior fires far better than frame construction. Its resistance to interior fires is about the same as frame construction but if not properly fire-stopped difficulty may be

experienced in extinguishing fires behind the brick facing. Veneered structures are dry and easy to heat.[1]

**Interior Surfaces.** — The interior surfaces of exterior wood-stud walls and both surfaces of wood-stud partitions are usually constructed of wood or metal lath, plaster board or fiber board to form the base for plaster, as shown in Figs. 63*d*, *f*, and *i*. Plaster is applied as described in Article 80. Partitions may also be constructed of matched ceiling placed on one or both sides of wood studs as shown in Fig. 63*k*.

**Post and Girt Construction.** — In cheap and temporary buildings the structural elements in frame walls and partitions may consist of widely-spaced horizontal members, called *girts*, running between wood posts which are the load-carrying elements. Girts are usually $2 \times 4$-in. members spaced 3 or 4 ft. apart.

**Exterior Surfaces.** — For exterior walls the exterior surface may consist of vertical sheathing nailed to the girts, the cracks in the sheathing being covered with wood strips called *battens* placed on the outside as shown in Fig. 63*l*. Corrugated iron, as described more fully in Article 40, is also used for such surfaces.

**Interior Surfaces.** — Exterior walls of this type are not usually provided with a finished interior surface. Temporary partitions are quite commonly made of ceiling, plaster board, or fiber board placed on one or both sides of wood girts with no other finish with the possible exception of paint on ceiling and calcimine on plaster board. See Fig. 63*m*.

Ceiling is usually tongued and grooved but may be ship-lapped and is finished with a bead or a V at the joint and in the center of the face as shown in Fig. 62*i* and *j*. Since there is always a bead or V in the center of the face, ceiling is called *double-beaded* or *double-V;* or *bead and center bead* (*B*, and *C*, *B*) or *V and center V* (*V* and *C*, *V*). If the beads or V's are on both sides, as shown in Fig. 62*k* and *l*, it is called *two-side ceiling.* Ceiling is 4 in. and 6 in. (nominal) wide and from $\frac{5}{16}$ to $\frac{11}{16}$ in. (actual) thick, the most common width is probably 4 in. and thickness $\frac{9}{16}$ in. The two-side ceiling would ordinarily not be used with girts but is particularly useful for the type of non-bearing partition, shown in Fig. 63*n*, where the ceiling is supported only at the top and bottom.

## ARTICLE 29. TIMBER COLUMNS

Timber columns are usually composed of a single piece varying in size from 4 in. by 4 in. upwards. Large timbers may have a hole bored along the axis as shown in Fig. 64*a* to enable the piece to season more uniformly throughout the entire section and thus avoid radial cracks to a certain

[1] Report of Building Code Committee of U. S. Department of Commerce.

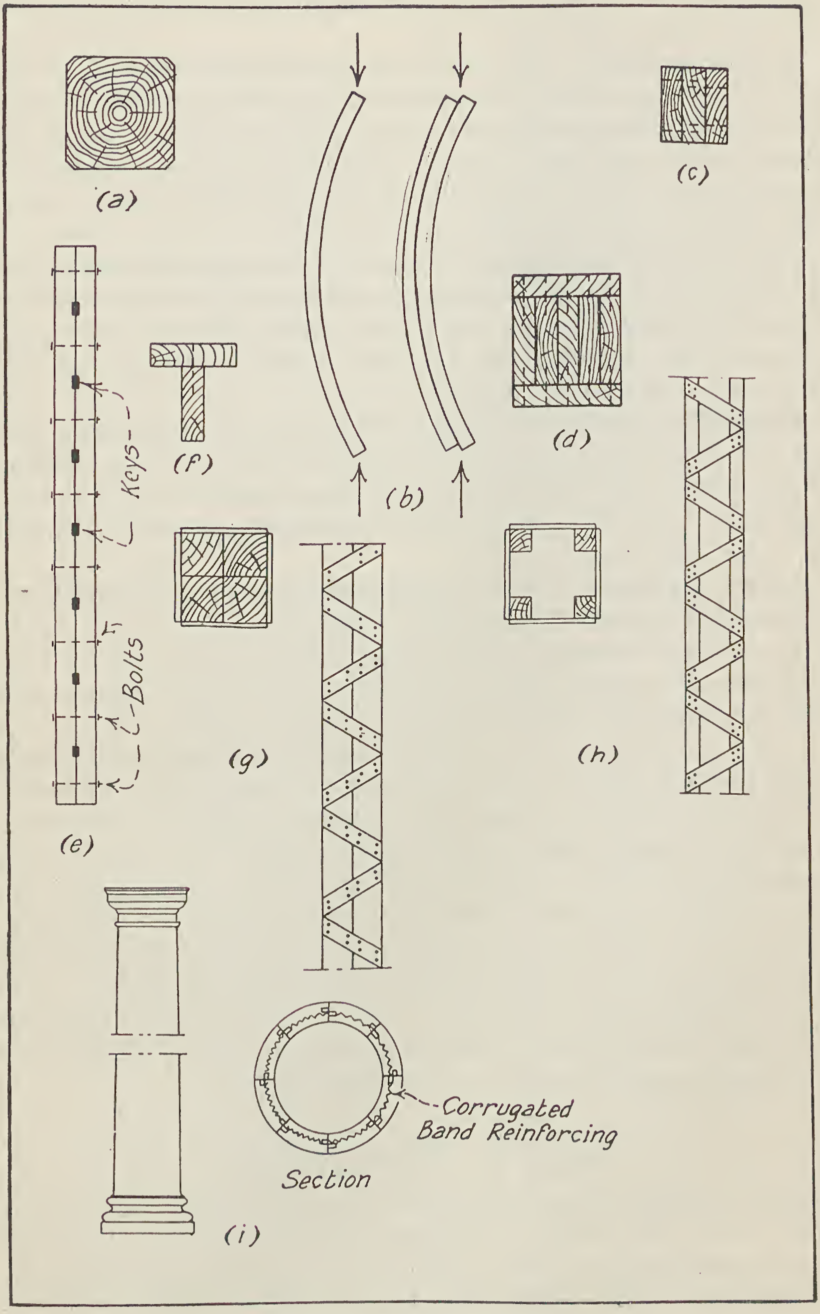



FIG. 64. Timber Columns

extent. The corners may also be *chamfered* as shown in this figure to make the columns more resistant to fire and to improve their appearance.

If a single piece of sufficient size is not available several pieces may be spiked or bolted together. A column built up in this way is not as strong as a column of the same size composed of a single stick because the various pieces tend to act separately and not together as a unit. The action of a column consisting of one piece and of a column consisting of two pieces is illustrated in Fig. 64*b*. It will be noted that in the column consisting of two pieces those pieces tend to slide on each other and act as separate pieces. Pieces fastened together by nails or bolts as shown in Fig. 64*c* do not act as a unit. The arrangement shown in Fig. 64*d* is better. The use of metal keys as shown in Fig. 64*e* is quite effective in keeping the members from sliding on each other but involves a considerable amount of labor. In this type of column the members must be held in contact by bolts as shown in the figure.

In the construction of forms and scaffolding the T-section built up of two pieces as shown in Fig. 64*f* is more effective than a section using the same two pieces placed flat against each other.

Four pieces may be fastened together by timber lacing strips as shown in Fig. 64*g* or they may be spaced some distance apart and fastened by lacing strips as shown in Fig. 64*h* in long columns where rigidity is an important factor.

In slow-burning or mill construction the columns are of a single piece which must be at least 8 in. by 8 in. in section even though the load may not require a column that large.

Built-up wood columns as shown in Fig. 64*i* are extensively used to carry out architectural effects and not primarily to carry loads.

## ARTICLE 30. TIMBER BEAMS AND GIRDERS

The simplest and most common form of timber beam or girder consists of a single piece as shown in Fig. 65*a*. It may be as small as 2 in. by 4 in. for light ceiling joists or rafters in residences and as large as 12 in. by 24 in. where very heavy loads are to be carried over long spans. In slow-burning or mill construction, beams with a width less than 6 in. and a depth less than 10 in. are not permitted.

Very often a single piece of the required strength cannot be obtained or it may be more convenient to fasten several pieces together as shown in Fig. 65*b* forming a *built-up beam* the pieces being set on edge. If the pieces are only 2 in. thick they may be spiked together but for larger pieces bolts are usually required. If such beams are to be exposed to the weather, water will soak in between the pieces and cause them to rot.

For this reason *separators* may be used as shown in Fig. 65*c*. Separators also permit heavy timbers to season more readily and the danger of dry rot is avoided. The use of separators on the interior of buildings is objectionable, for fire in the small space between pieces would be very

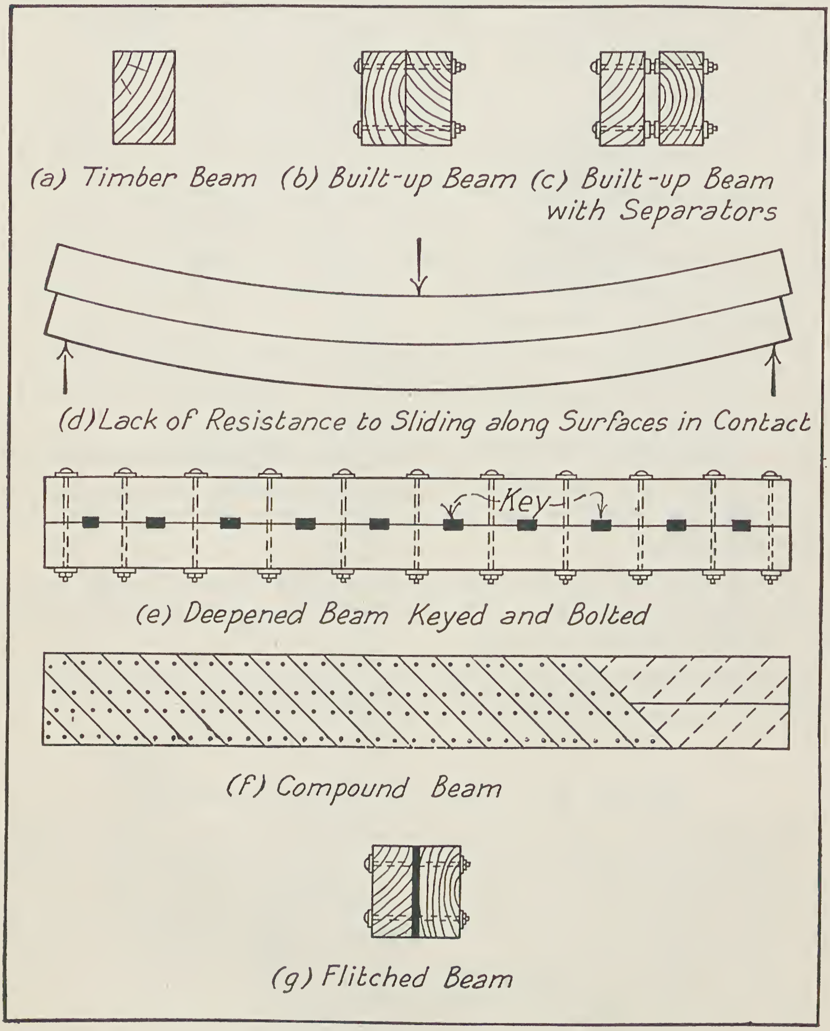



Fig. 65. Timber Columns

difficult to put out. If heavy timbers are placed in contact with each other the surfaces of contact should be given some preservative treatment to prevent dry rot. Beams built up in this way are very satisfactory and are often stronger than beams of the same size made of one piece,

for a defect which exists in one piece of a built-up beam is not likely to come directly opposite defects in other pieces, while if a beam is composed of a single stick a defect may exist throughout the entire width and seriously weaken the beam.

If one piece of timber is placed on top of another to act as a beam these pieces will slide on each other along the surface of contact as shown in Fig. 65*d* when a load is applied. If this sliding is prevented so that the

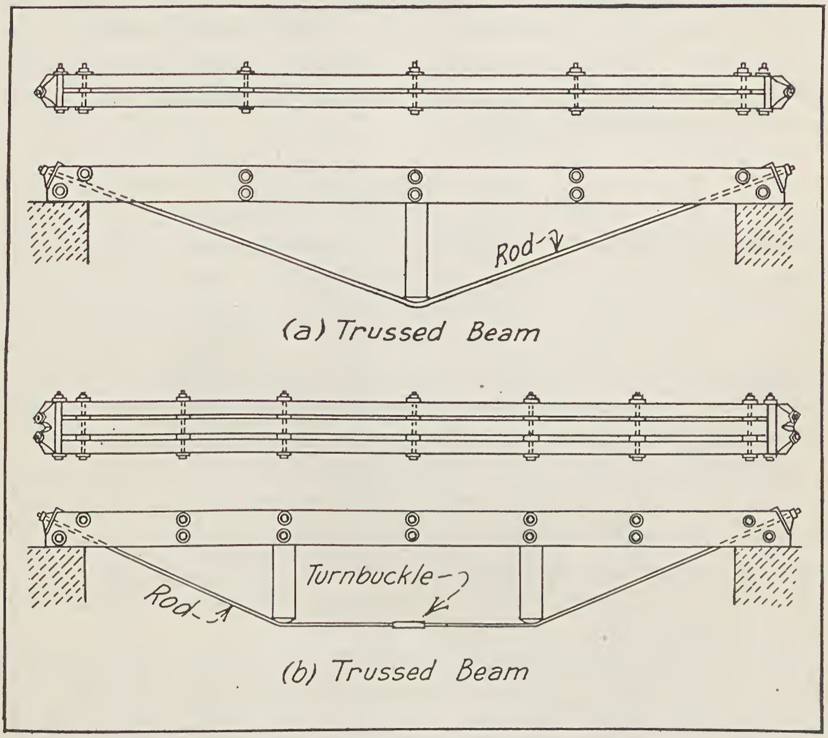



FIG. 66. Trussed Beams

two pieces act as a unit the beam thus formed will be equal in strength to a beam of equal size composed of a single piece. Bolts or spikes do not prevent this sliding but hardwood or metal keys as shown in Fig. 65*e* give satisfactory results if properly designed and constructed. It is also necessary to provide vertical bolts to hold the pieces in contact as shown in figure. This type of beam is called a *deepened beam.* Another method of accomplishing the same result is by the use of diagonal boards nailed to the sides of the pieces as shown in Fig. 65*f*. This method is not as effective as that making use of keys but may be more easily accomplished. Built-up beams of these types are rarely used.

Beams may be built up of timbers set on edge with steel plates between them, the several pieces being bolted together as shown in Fig. 65*g* to form *flitched beams.* Such beams are uneconomical but they are used to a limited extent to meet special conditions.

*Trussed beams* as illustrated in Figs. 66*a* and *b* are very satisfactory types and are extensively used. The type shown in Fig. 66*a* is sometimes called an *inverted king-post truss* and that shown in Fig. 66*b* an *inverted queen-post truss.* The end connections for the rod may be made of cast iron as shown in the figure or they may be built up of structural steel sections. Two rods may be used instead of one rod as shown. The top member may be built up of several thicknesses of two-inch material spliced by staggering the joints.

## ARTICLE 31. TIMBER TRUSSES

**Make-up of Members.** — The various types of trusses are discussed in Article 26. The upper chord is always made of timber and may be a single stick, several pieces placed side by side, or several pieces placed one on top of the other as in curved chord trusses. The lower chord may be a single stick, several pieces placed side by side, or steel rods. The other members which carry compressive stresses are made of one or more pieces of timber and those which carry tensile stresses are made of steel rods.

**Truss Joints.** — The joints in timber trusses are made in many ways some of which are by cutting the members so that they fit into each other in such a way as to provide for the stresses, bolts being used where necessary to hold the members together; by using steel *connection* or *gusset* plates and lag screws or bolts; and by using specially-shaped cast-iron or timber blocks.

The end joints are usually the most difficult ones to design and construct. The simple type shown in Fig. 67*a* is only suitable for use where the stresses are small. The joint tends to fail by bearing on the end of the inclined member and by shearing along the dotted plane. The length *a* must be made great enough to provide an area sufficient to resist the tendency to shear. This is not usually feasible if the stresses are large. The bolts must be large enough to hold the joint together but do not assist directly in transmitting stress.

The end joint shown in Fig. 67*b* is more elaborate but depends upon the same principles as that shown in Fig. 67*a*. The inclined member is more effective in bearing and the area resisting shear is larger than in the previous detail. A part of the shearing tendency is exerted on the upper dotted area but the lower area must carry the full shearing stress. The short member on the lower side is called a *bolster*. It is provided to make

the joint more substantial but does not carry any calculated stress. The diagonal bolts which are provided to hold the joint together pass through the bolster at an angle and tend to make it slide along the horizontal member. This tendency is resisted by hardwood keys as shown in the figure.

An end joint using steel gusset plates is shown in Fig. 67*c*. One gusset plate is placed on each side of the joint. These plates are preferably fastened to the members by means of lag screws instead of bolts as it is difficult to bore the holes in the timber so accurately that the bolts

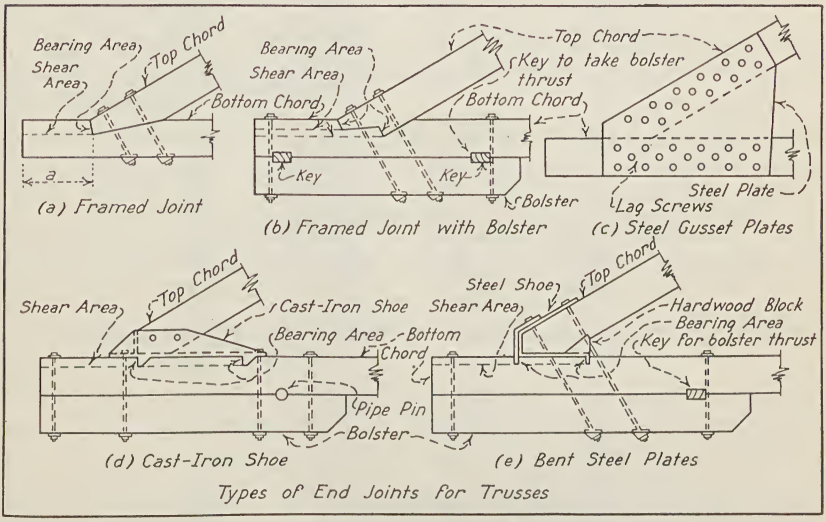



Fig. 67. End Joints for Timber Trusses

passing through are plate and the holes in the timber will fit the holes in the other plate without forcing the bolts in such a way as to impair the strength of the connection. The joint depends for its strength upon the lateral strength of the lag screws inserted in the timber.

The use of a cast-iron block in an end joint is illustrated in Fig. 67*d*. The projections or lugs on the lower side of this block must have sufficient bearing area so that the wood will not be overstressed and there must be enough length between the lugs and the end of the member so that the joint will not fail by shear along the dotted plane. Since there are no inclined bolts used the bolster does not tend to slide and no keys are required between the bolster and the horizontal member. A pipe key or pin is used however. The bolster does not carry calculated stress but makes the joint more substantial.

An end joint making use of bent steel plates in place of the cast-iron joint described is shown in Fig. 67*e*.

The joint at the peak or apex of a truss is quite simple for the horizontal thrusts or stress components of the chord members balance each other. The vertical thrusts or stress components of the chord members

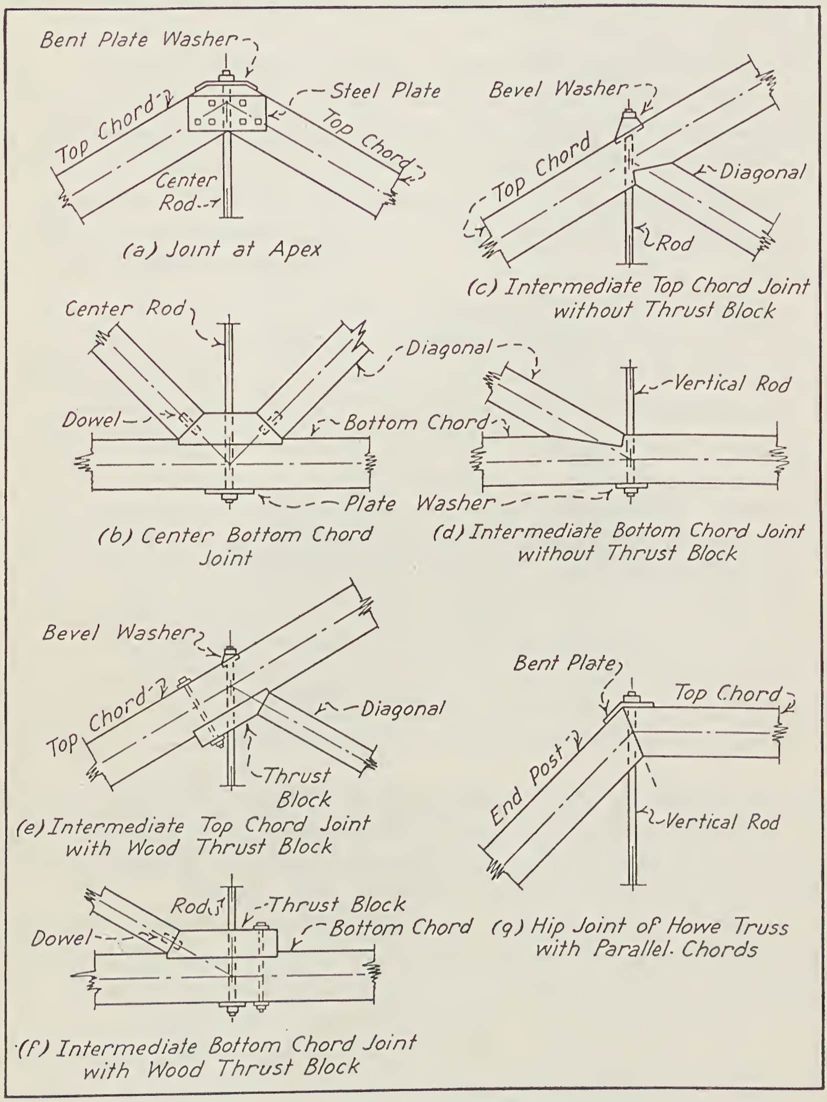



Fig. 68. Intermediate Joints for Timber Trusses

are balanced by the stress in the vertical rod in the center of the truss. This stress is transmitted through a plate or bent washer at the apex as shown in Fig. 68*a*. Steel or wood plates are bolted to each side of the truss at the joint to assist in holding the chords in position.

The center joint on the lower chord is also a simple joint for the chord stresses on each side balance each other and are not transmitted through the joint if the chord is not spliced at this joint. The horizontal thrusts or stress components of the diagonal members meeting at this joint balance each other and the vertical thrusts or stress components are equalized by the stress in the center vertical rod. The ends of the diagonal members bear on a timber or cast-iron *thrust block* and are held in position by *dowels* as shown in Fig. 68*b*. The thrust block is usually set a short distance into the chords. A washer or plate is placed on the end of the vertical rod.

Other diagonal members bearing on the top or bottom chord carry relatively small stresses and may be notched into the chord as shown in Figs. 68*c* and *d*.

Intermediate joints on the top and bottom chords may make use of wood thrust blocks as shown in Figs. 68*e* and *f* or cast-iron thrust blocks must be used. The thrust blocks must be set deep enough into the chords so that the bearing at the end of the block is sufficient to take the component of the stress in the diagonal member in the direction of the chord.

A detail for the hip joint of a howe roof truss with parallel chords is shown in Fig. 68*g*.

The simplest form of timber roof truss is shown in Fig. 69*a*. It is only suitable for spans of 20 or 30 ft. Other simple forms of timber truss are the *king-post truss* shown in Fig. 69*b*, the *queen-post truss* shown in Fig. 69*c*, the *inverted king-post truss* shown in Fig. 66*a* and the *inverted queen-post truss* shown in Fig. 66*b*. These inverted trusses are commonly called *trussed beams* and are described in Article 30.

A Howe roof truss with inclined top chords is shown in Fig. 70 and a howe truss with parallel chords in Fig. 71*a*.

A bowstring roof truss is illustrated in Fig. 71*b*. The top chord consists of 2 sets of 2-in. timber bolted together and forming a laminated member. The end joint makes use of a steel plate bent in the form of a U to receive the top chord and fasten to the lower chord. The web members in this form of truss carry very little stress so it is not serious if the center lines of the members do not meet in a point at the joints.

The lattice truss shown in Fig. 71*c* makes use of 2-in. material bolted or tree-nailed together. The design of trusses of this type is largely empirical.

A lattice truss with a curved chord is illustrated in Fig. 71*d*. The truss shown in the figure is manufactured by the McKeown Brothers Company of Chicago at the building site or at the factory. They are shipped "knocked down." Trusses of similar design are made by others.

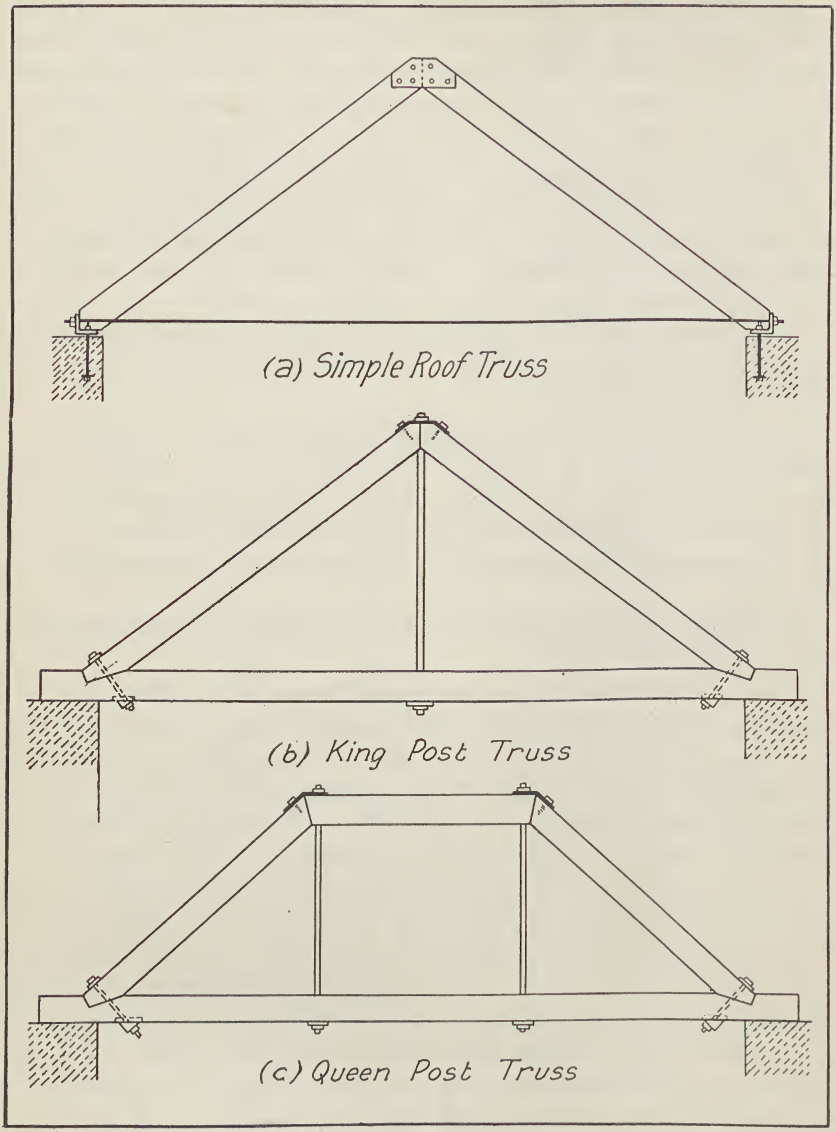



Fig. 69. Simple Roof Trusses

**Lateral Bracing for Trusses.** — It is very essential that trusses be braced in a direction perpendicular to their length to keep them from failing by buckling and twisting. This is particularly true of the top chord which should be supported laterally at frequent intervals. This will usually be taken care of by the roof deck. The bottom chords

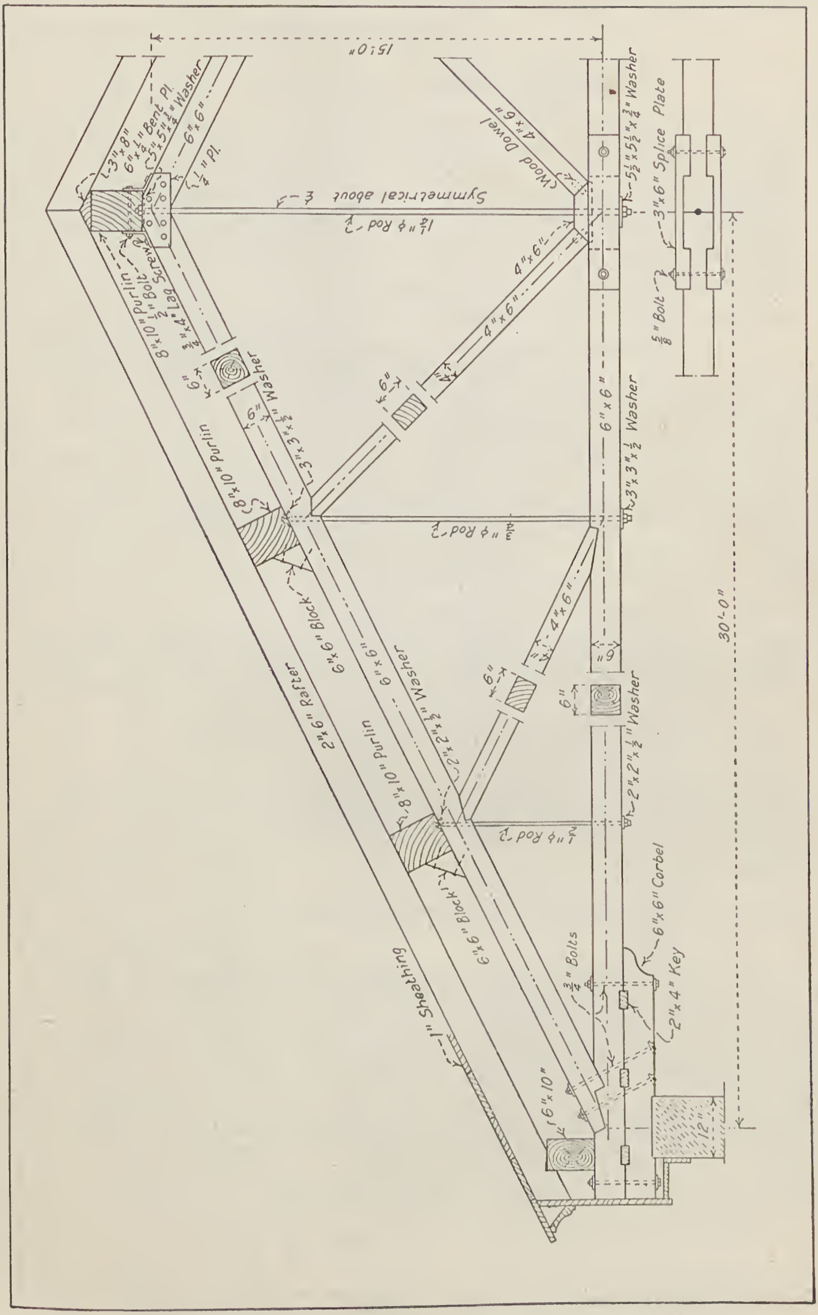



FIG. 70. Howe Roof Truss

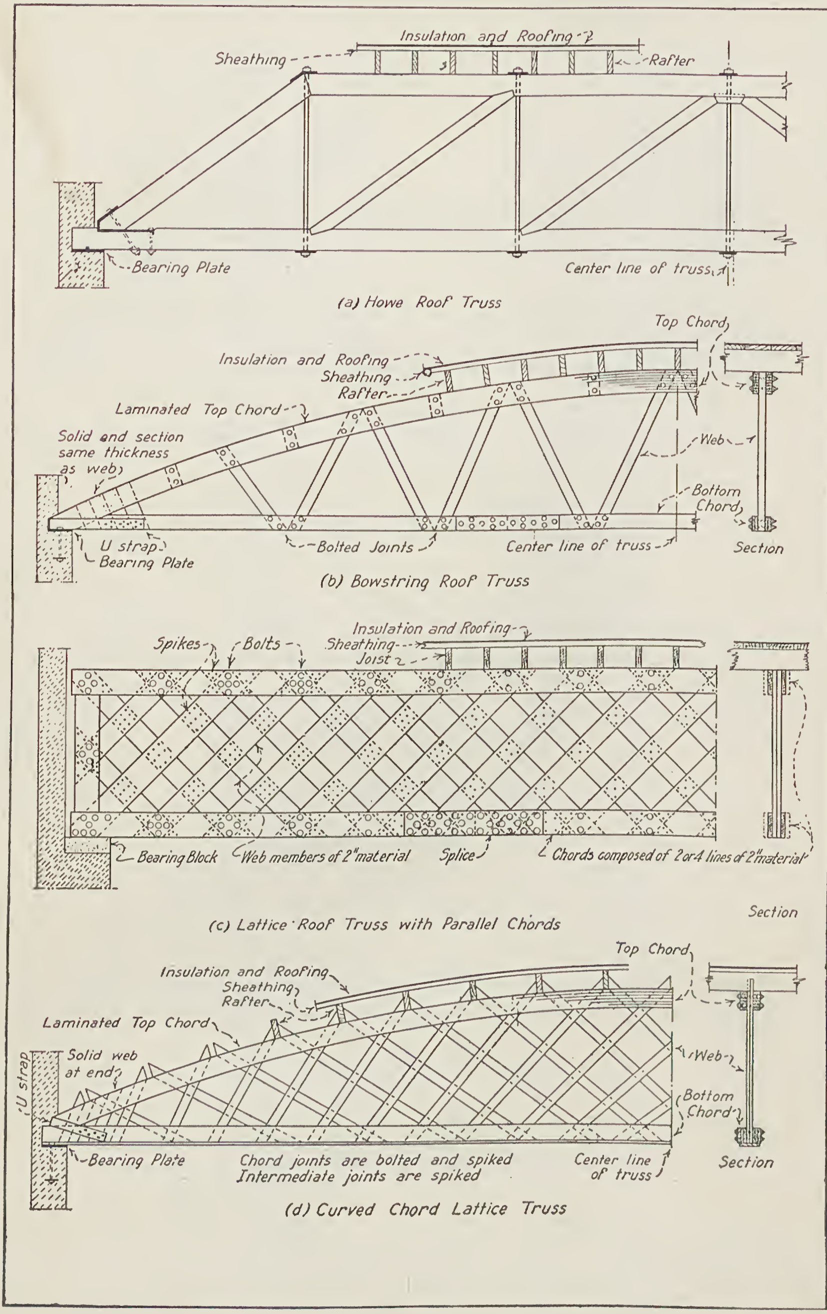



FIG. 71. Examples of Timber Roof Trusses

should be braced by lines of light trussed bracing in vertical planes perpendicular to the main trusses.

## ARTICLE 32. TIMBER ARCHES

Timber arches are occasionally used to support the roofs over large floor areas such as those required for drill halls, riding halls, gymnasiums, exhibition halls, and auditoriums where the spans are too great for the economical use of timber trusses and where steel trusses or arches are not used on account of their greater cost.

The usual type is the three-hinged arch as illustrated in Figs. 72*a* and *b*. The type of joint shown in Fig. 72*a*[1] is the most common but steel gusset plates as shown in Fig. 72*b*[2] are sometimes used.

The simple arch shown in Fig. 73*a* is suitable for short spans symmetrically loaded but the timber trusses shown in Fig. 71 are preferable because of the support which the web members give to the curved top members. This type of arch is practically a two-hinged arch because there is very little restraint at the ends. The arch ring is made up of planks sprung into the desired curve and bolted together. For uniform loads the curve of the arch ring should be a parabola with its axis vertical.

A type of arch which has been used is shown in Fig. 73*b*. The upper and lower members are built up of planks bolted together, the diagonal web members are single sticks and the radial web members are steel rods.

## ARTICLE 33. NAILS, SCREWS AND BOLTS

This article will consider various methods used in holding the timber parts of a building together. All of the devices considered are not used in framing a structure but many are included which are used on such parts as interior finish. For instance, large nails and spikes are used in framing but finish nails are not. However, it is convenient to consider finish nails in this article.

**Nails.** — Nails commonly used in building construction may be divided into two general classes, *wire nails* and *cut nails*. The size of nails is designated thus, 8d or 16d, called 8 penny or 16 penny. This method of designation originated in the cost per 100 nails but no longer has this significance.

*Wire nails* are formed from steel wire of the same diameter as the nails. The common forms of wire nails are shown in Fig. 74*a* to Fig. 74*c*. Common nails are used where there is no objection to the exposed head and where the wide head is desirable, as in framing, sheathing, subfloors, etc.

[1] Timber Framing, by Henry D. Dewell, Dewey Publishing Co.

[2] H. W. Sheley, Engineering News-Record, Vol. 80, p. 595.

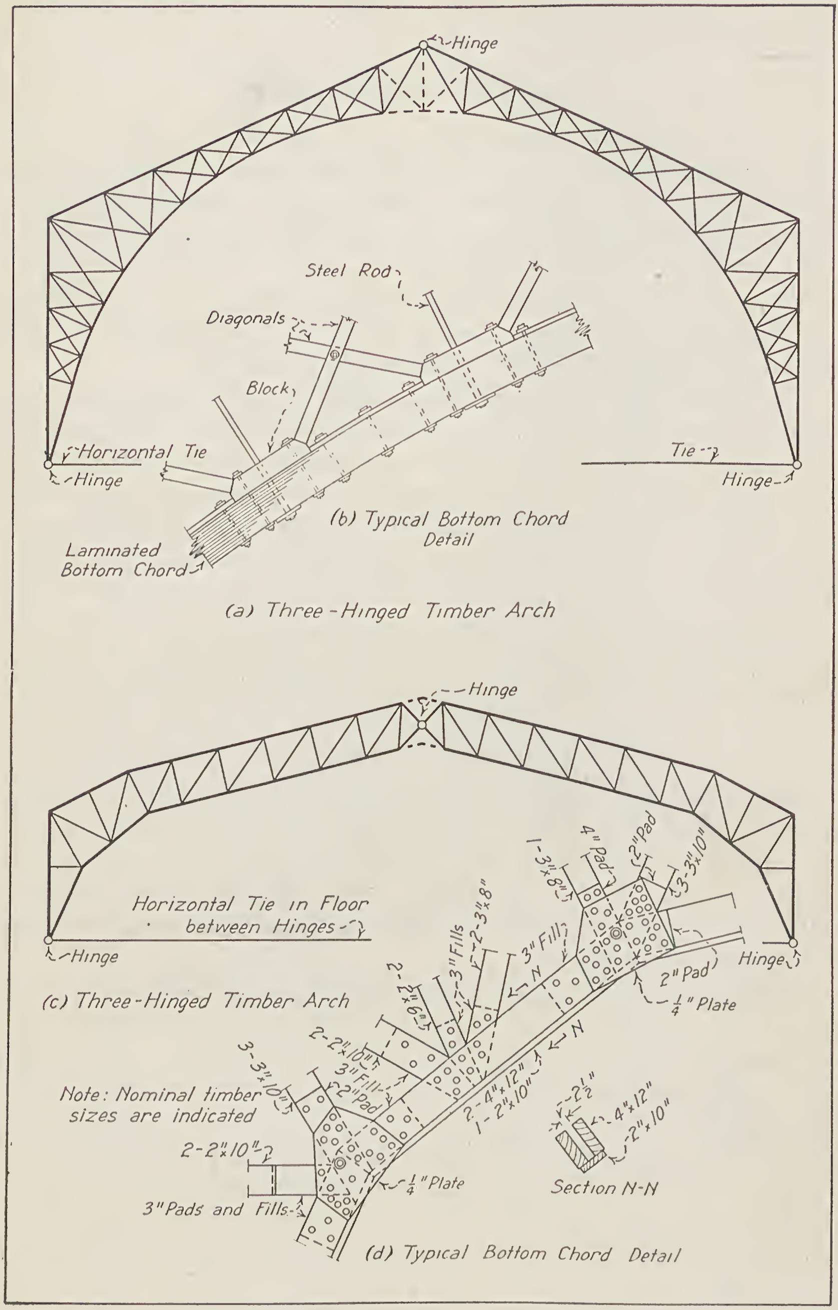



Fig. 72. Three-hinged Timber Arches

*Casing nails* are used principally with matched flooring, ceiling, and drop siding. *Finish nails* are used with interior and exterior finish, the heads being sunk below the surface with a *nail set* and the hole thus formed being filled with putty to conceal the nails. Common nails vary in size from 2d with a length of 1 in., to 60d with a length of 6 in.; casing nails from 2d with a length of 1 in. to 40d with a length of 5 in.; and finish nails from 2d with a length of 1 in. to 20d with a length of 4 in.; the diameter varying with the length. A *barbed flooring nail* is illustrated in

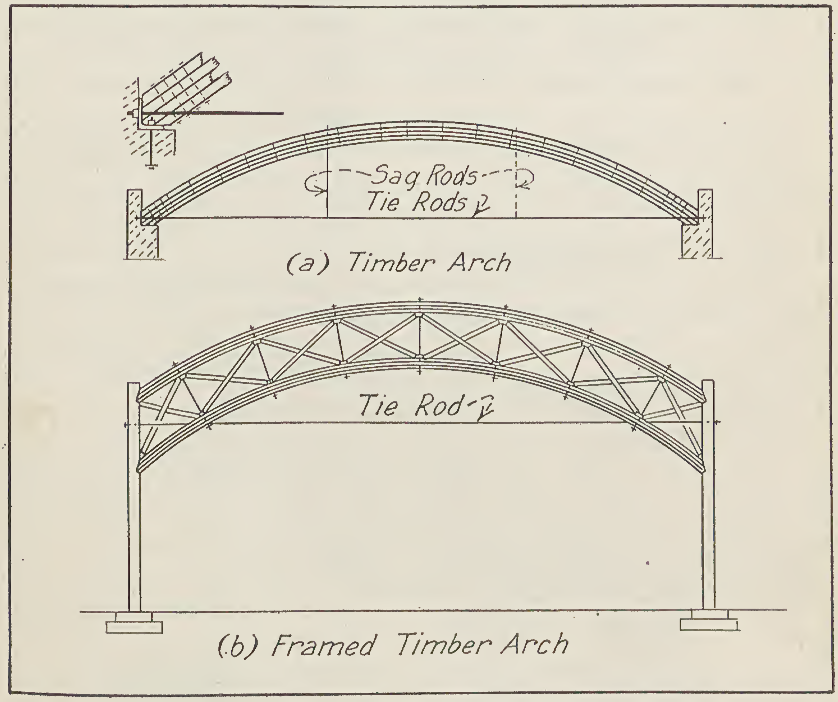



FIG. 73. Simple Timber Arches

Fig. 74*d*. *Shingle* and *lath nails* are small nails of the same shape as common nails. *Wire spikes* are of the same general shape as common nails, but they may have diamond or chisel points and flat or convex heads. Their size is designated by the length in inches and varies from 6 in. to 12 in. Wire nails, plain or galvanized, with large heads, are made for use with prepared roofing, galvanized nails are made for tile and slate roofing and cement coated nails are made for use where resistance to withdrawal is an important factor. Various other types of wire nails are on the market.

*Cut nails* and spikes as shown in Fig. 74*e* are stamped out of steel

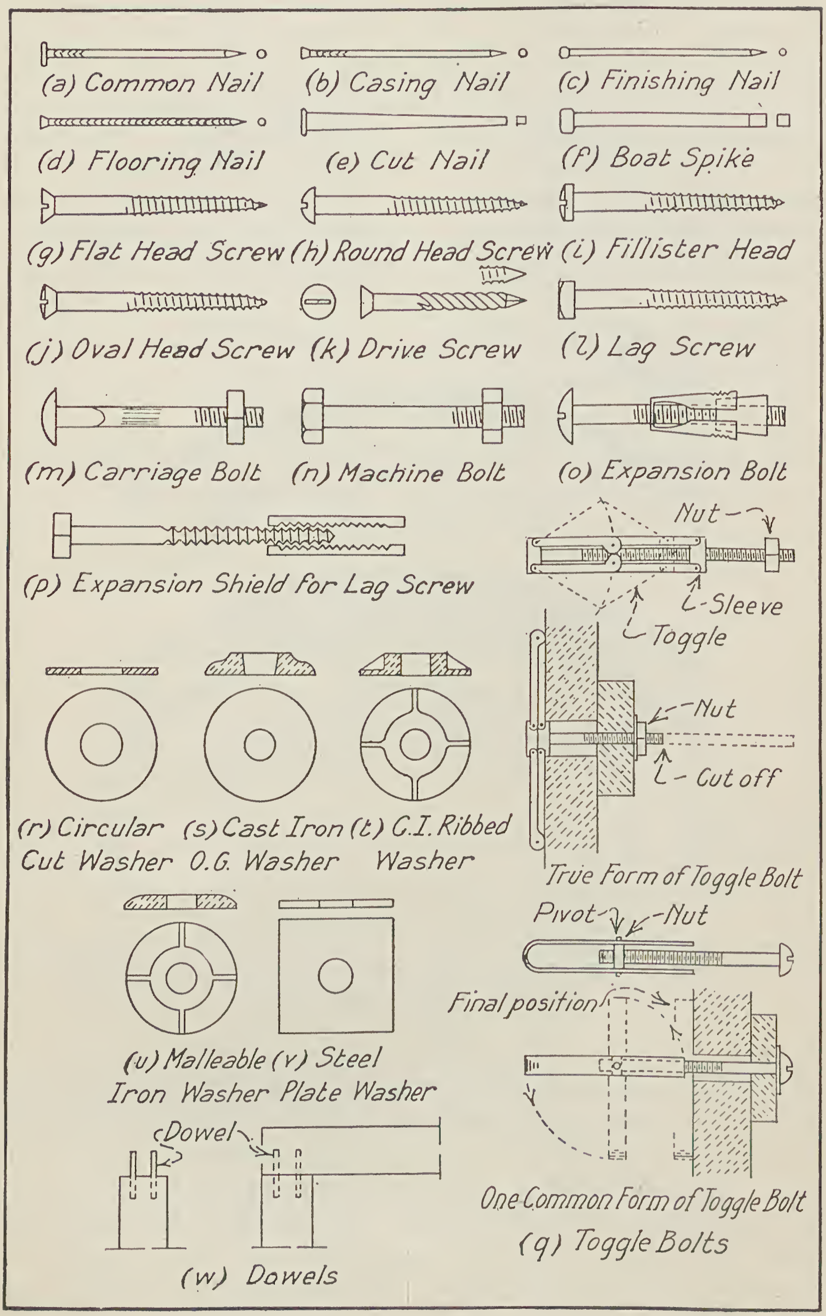



Fig. 74. Nails, Screws, Bolts and Washers

plates of the same thickness as the nail. Various sizes and shapes are manufactured to correspond with wire nails and spikes.

The initial holding power of cut nails is greater than that of wire nails but the holding power when partly withdrawn is less. Wire nails are more easily driven than cut nails and cause less splitting of the wood and for this reason are much more widely used. Cut nails have a greater length of life when exposed than wire nails.

*Boat spikes* are made of square bars of steel or wrought iron. They have a wedge-shaped point and a head as shown in Fig. 74*f*. The size of boat spikes varies from ¼ in. sq. by 3 in. in length to ½ in. sq. by 12 in. in length. Boat spikes are used in heavy timber framing.

**Screws.** — Screws may be divided into two general classes, i.e., wood screws and lag or coach screws.

*Wood screws* may be made of steel, brass, or bronze. Steel wood screws may have the natural steel finish called bright or they may be blued, nickel-plated, bronzed, lacquered, galvanized, or tinned. The various forms of wood screws are shown in Fig. 74*g* to Fig. 74*k*. They all have the slotted head so that they may be driven with a screw driver and with the exception of the *drive screw* they have gimlet points. Drive screws have diamond-shaped points and steep-pitched threads so that they may be driven with a hammer. The size of wood screws is designated by the length and gage, several gages being available in each length. Wood screws vary from ¼ in. to 6 in. in length. They have a great variety of uses in building construction.

*Lag screws* have a conical point and a square head. *Coach Screws* have a gimlet point and square head as shown in Fig. 74*l* but both forms are commonly called lag screws. The size of lag and coach screws is designated by the diameter and length of the shank, both being expressed in inches. The lengths vary from 1¼ in. to 12 in. and the diameters from ¼ in. to 1 in. Lag screws are used for heavy timber framing.

A hole should usually be bored for screws to avoid splitting and to make driving easier. This hole should be somewhat smaller than the diameter at the root of the thread.

**Bolts.** — Bolts used in building construction may be divided into the following classes: carriage bolts, machine bolts, and drift bolts.

*Carriage bolts* have a round head shaped as shown in Fig. 74*m*, and a square nut. The portion of the shank immediately under the head is square and the remainder of the shank is round. The square portion of the shank when embedded in a timber prevents the bolt from turning while the nut is being turned. The size is designated by the length of shank and diameter in inches. Carriage bolts may be obtained in almost any size. They are used in bolting pieces of timber together and where

the square portion of the shank will be embedded in timber. Cut washers are usually used under the head and nut to give greater bearing area.

*Machine bolts* may have square or hexagonal heads and nuts as shown in Fig. 74*n*. The shank is round throughout its entire length. The size is designated by the length of shank and the diameter in inches. Machine bolts are available in almost any size. They are used for bolting steel and cast-iron members to timber and for bolting steel members together during erection or permanently in some cases.

A *drift bolt* is defined by Professor Jacoby[1] as a piece of round or square iron or steel, with or without head or point, driven as a spike. Drift bolts are used in heavy framing. Before driving, a hole must be bored somewhat smaller than the drift bolt.

*Expansion bolts* are of many different forms but in all forms a special nut is used which is so designed that after insertion in a hole the process of turning the bolt will so enlarge or expand the nut that it cannot be withdrawn. One form is illustrated in Fig. 74*o*. Expansion shields for use with lag screws as shown in Fig. 74*p* are commonly used. Expansion bolts are used to fasten wood or iron to masonry, which is already in place.

*Toggle bolts* of various forms are on the market. The head in all cases is so arranged that after the bolt has been inserted head first in a hole until the head is free on the other side of the piece, it will rotate or open up in such a manner that it cannot be pulled back through the hole. Two forms of toggle bolt are illustrated in Fig. 74*q*. Toggle bolts are used in cases where bolts cannot be inserted in the usual way on account of one face being inaccessible.

**Washers.** — Washers are used under the head and under the nut of a bolt in timber construction to provide a larger bearing area and prevent the crushing of the wood fibers. Washers are of five types, various sizes being available in each type to suit the various sizes of bolts. These types may be listed as follows: Circular *cut washers* as shown in Fig. 74*r*, cast-iron *O. G. washers* as shown in Fig. 74*s* the name being derived from the O. G. curve of the sides; cast-iron *ribbed washers* as shown in Fig. 74*t*, *malleable iron washers* as shown in Fig. 74*u*, and steel *plate washers* as shown in Fig. 74*v*, the latter being made special to suit each case.

**Dowels.** — *Dowels* are steel or wooden pins extending into, but not through, two members of a structure to connect them as shown in Fig. 74*w*. A *tree-nail* is similar to a wood dowel but it is used in such a manner that one or both of its ends are exposed.

[1] Structural Details, by H. S. Jacoby. John Wiley & Sons, Inc., 1909.

## ARTICLE 34. TIMBER FRAMING

Timber members may be fastened together by nails and spikes, screws, or bolts; by cutting the members to form joints, which may be fitted together making use of bolts or dowels to hold them in place; or by steel plates and straps, or iron castings specially shaped to suit each case, and used in connection with bolts. The present tendency is to avoid the types of joints which require a large amount of labor and to use bolts, spikes, plates and castings as much as possible. The joining of small pieces of lumber in placing the finish and in building book cases, cupboards, panels, etc. is classed as finish carpentry and millwork and not as timber framing but the joints used in this work will be included in this article.

**Side Joints.** — The joints between two members placed side by side are called *side joints.* Such joints may be used in flooring, siding, panels,

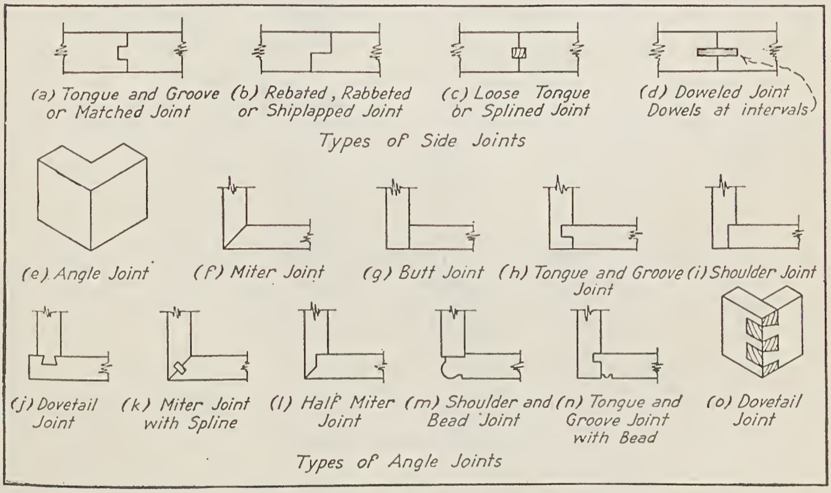



Fig. 75. Side and Angle Joints for Wood

and millwork of various kinds. The common types are the *tongue-and-groove* or *matched joint*, the *rebated*, *rabbeted*, or *ship-lap joint*, the *loose-tongue* or *spline joint*, and the *doweled joint* as shown in Fig. 75*a* to *d*.

**Angle Joints.** — In millwork and cabinet work two pieces which meet at right angles, as shown in Fig. 75*e*, may be joined by means of the *miter joint*, the *butt joint*, the *tongue-and-groove* or *matched joint*, the *shoulder joint*, or the *dove-tail joint* or various modifications of these joints, as shown in Fig. 75*f* to *o*. The *bead* shown on the shoulder joint and the tongue-and-groove joint casts a shadow which hides the crack where the two members join. These joints are glued where possible but

if nails are necessary, finish nails with small heads are used. The nail heads are driven a short distance below the surface by using a nail set and the hole thus formed is filled with putty after the priming coat of paint or varnish is on.

**Framed Joints.** — The following types of joints are designed for members which frame into each other at an angle but are rarely used on account of the amount of labor involved in their construction:

A *mortise-and-tenon joint,* as shown in Fig. 76*a*, consists of an opening called a *mortise* in the side of one piece into which fits the specially shaped end, called a *tenon,* of the other piece. The tenon may be fastened into the mortise by means of a wood or steel pin.

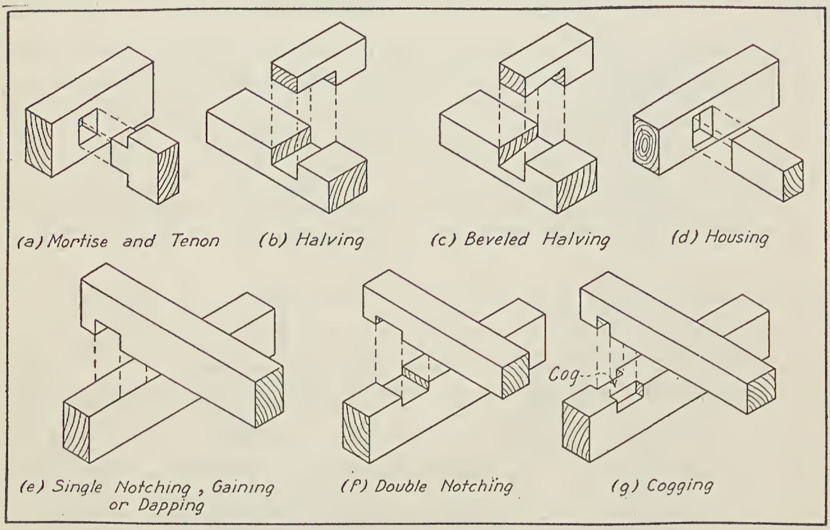



Fig. 76. Timber Joints

*Halving* consists of joining two members, which meet or cross each other at an angle, by cutting a similar notch in each so that they will be flush on one face if they are not of the same thickness and on both faces if the pieces are of the same thickness. See Fig. 76*b*. If the members are beveled as shown in Fig. 76*c* to assist in holding them together the operation is called *beveled halving.*

*Housing* consists of letting the entire end or thickness of one member into the side of another as shown in Fig. 76*d*.

*Notching* consists of cutting a depression the full width of one member to receive another member as shown in Fig. 76*e*. If both of the members are cut away as shown in Fig. 76*f* the process is called *double notching.* The terms *gaining* and *dapping* have the same meaning as notching.

*Cogging*, as shown in Fig. 76*g*, is similar to double notching but the depression on the face of one member does not go all of the way across. The uncut side of the face forms a ridge across the depression. This ridge is called a *cog*. The cog may be in the middle or on either side.

**Splices or Longitudinal Joints.** — Timbers may be *spliced* or joined together longitudinally by lapping, scarfing, or fishing. The most common method is fishing but the more simple forms of scarfing are used occasionally.

*Lapping* consists simply of lapping the end of one member over that of the other and fastening them together in some manner such as bolting. See Fig. 77*a*. This type of joint is not suitable for members carrying stress because of the large eccentricity introduced.

*Scarfing* consists of shaping the ends of the two members so that they may be fitted together and fastened without increasing the size at the joint. The simplest form of scarf joint is shown in Fig. 77*b*. It is called *half-lap scarf joint* and is suitable for compression members.

The resistance of a scarf joint to tensile stresses can be increased in several ways which make it necessary to shear off one or more blocks of timber before the joint could fail. This is accomplished by inserting *keys* as in Fig. 77*c*, by *bevels*, or by *tables* as in Fig. 77*d* and *e*. In all of these cases failure may occur in the joint or at the weakened sections at the ends of the joints.

*Fishing* consists of joining two pieces by means of wood or steel *fish plates* as shown in Fig. 77*f*. The ends of the members butt together instead of lapping as in scarf and lap joints. The simple form of joint is satisfactory for compression members where the function of the fish plates is to hold the members in line. Where tensile stresses are to be transmitted the *tabled fish-plate joints* shown in Fig. 77*g* may be used. Before these joints can fail it is necessary to shear off the tables on one side of the joint. They can be so proportioned that they will develop a shearing strength equal to the strength of the reduced section of the member. A tabled fish-plate joint with wood fish plates and one with steel fish plates are illustrated in Fig. 77*g*. The steel fish plates consist of large plates with smaller plates, forming the tables, riveted to them. A fish-plate splice with pins of steel pipe or hardwood taking the place of tables, is shown in Fig. 77*h*. The holes for the pins are bored after the joint is assembled.

In the *tenon-bar splice*, shown in Fig. 77*i*, steel bars take the place of fish plates. The bars which pass through the timber are rectangular in section and are designed as beams. The bearing area of the side of the bar must be sufficient to keep the bearing stresses against the timber within the allowable value and the hole for the bar must be located far

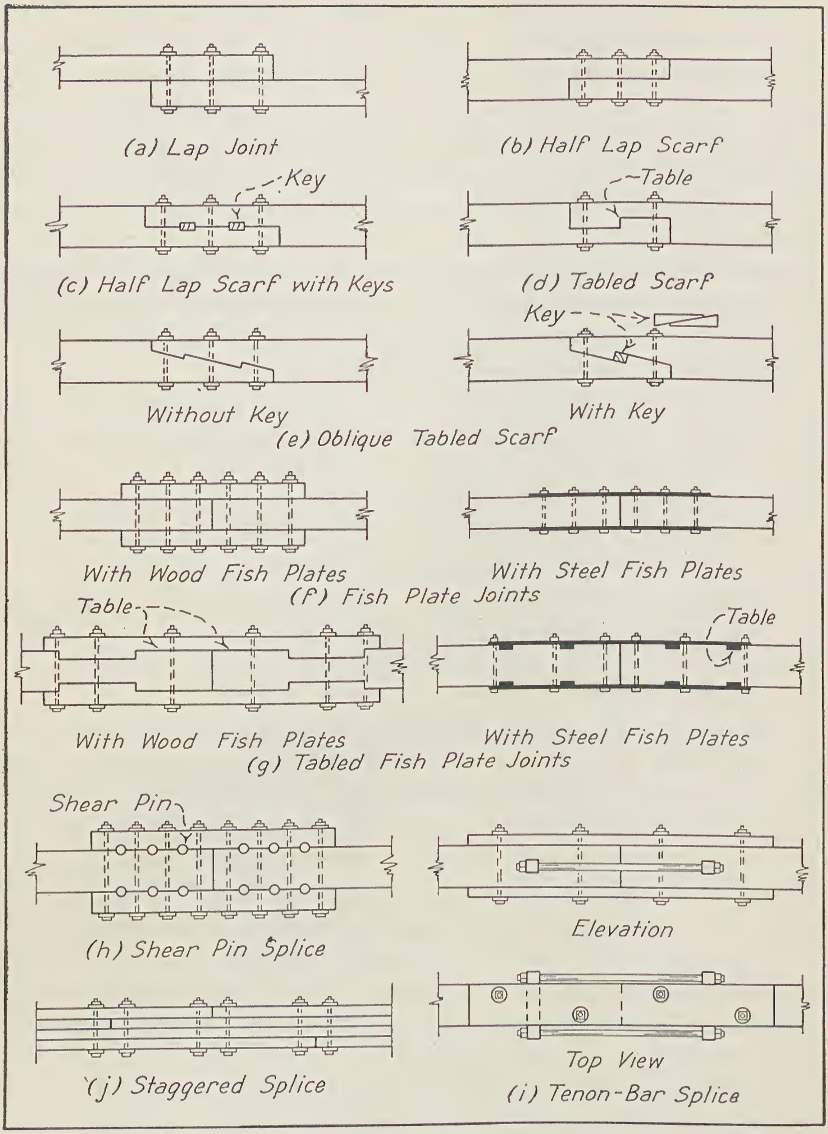



FIG. 77. Timber Joints and Splices

enough from the spliced end so that it will not shear the timber between the bar and the end.

Tension members are commonly built up of several planks bolted or nailed together. These may be spliced by *staggering* the joints as shown in Fig. 77*j*.

In all forms of joints the effect of the shrinkage of the timber may be

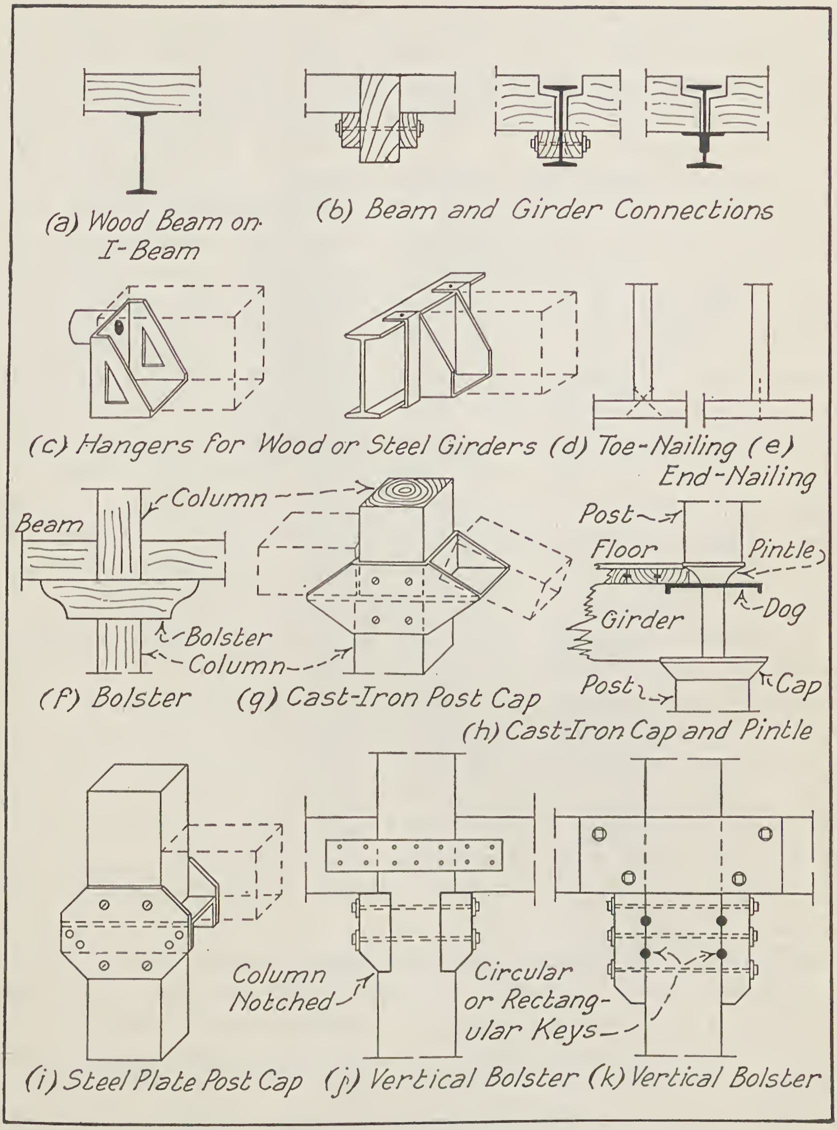



Fig. 78. Timber Beam and Girder Connection

quite serious. Joints which fit perfectly when made may open up and cause a redistribution of stress which the joint is not capable of carrying. This possibility should be kept in mind in selecting the type of joint and in design and construction.

**Beams and Girder Connections.** — Timber beams or joists may rest on top of timber or steel girders as shown in Fig. 78*a*; they may be supported

on wood strips or shelf angles bolted to the sides of timber or steel girders as shown in Fig. 78*b*; they may be supported on timber or steel girders by cast-iron or steel hangers as shown in Fig. 78*c* or in light construction, the joists may be *toe-nailed* into timber girders as shown in Fig. 78*d* or *end-nailed* as shown in Fig. 78*e*. For other details see Figs. 85 and 86.

**Connection of Beams and Girders to Columns.** — Timber girders may be supported at timber columns by using a hardwood *bolster* as shown in Fig. 78*f*; a cast-iron *post cap* as shown in Fig. 78*g*, a malleable cast-iron post cap with a *pintle* as shown in Fig. 78*h*, or a post cap formed of steel plates as shown in Fig. 78*i*. The detail shown in Fig. 78*j*[1] provides vertical bolster blocks set in notches in the side of the column and held in position by bolts. The notches may be replaced by circular or rectangular keys as shown in Fig. 78*k*.[1] These details are much superior to the horizontal bolsters shown in Fig. 78*f* for the bearing is on the end of the grain instead of the side and the effect of shrinkage is less. Caps designed to carry a girder on one side of a column are called one-way caps, those designed to carry girders on two opposite sides of a column are called two-way caps, and those which carry girders on all four sides are called four-way caps. For other details see Figs. 85 and 86.

It is usually desirable to use a post cap of such design that a girder which has burned in two will be released when falling and avoid pulling the entire column down. The caps shown in Figs. 78*g*, *h*, and *i* are of this type. The ends of girders may be tied together at the columns by *dogs* made of steel bars and shaped as shown in Fig. 78*h* by steel straps held in place by spikes or lag screws driven through holes provided in the straps; as shown in Fig. 78*j* or by wood planks held in place with bolts as shown in Fig. 78*k*. Some forms of post caps are so designed that ties are not required, provision being made in the caps for the insertion of bolts or lag screws to hold the girders in place.

Unprotected metal post caps are the most vulnerable feature in slow-burning construction from the standpoint of fire resistance. The cast-iron cap and pintle is superior to the steel plate cap from this point of view. Wood bolsters are usually permitted only for the support of roof girders.

**Wall Supports for Beams and Girders.** — Light timber joists are built into masonry walls as shown in Fig. 79*a* with ties placed at intervals of not over 6 ft. The ends of the joists are cut at an angle so that, in case of fire, they may fall without disturbing the walls.

If the ends of heavy timber girders are built into masonry walls without allowing a space at the sides and top for ventilation, dry rot will be quite certain to result causing the ends of the girders to rot off. To avoid

[1] Timber Framing, by Henry D. Dewell, Dewey Publishing Co.

this the construction shown in Fig. 79*b* may be used; a special metal box as shown in Fig. 79*c* may be provided; or a metal wall hanger as shown in Fig. 79*d* may be installed. Various methods have been devised to tie the girder to the wall and still enable it to be released in case of failure due to fire. See Fig. 79*e*.

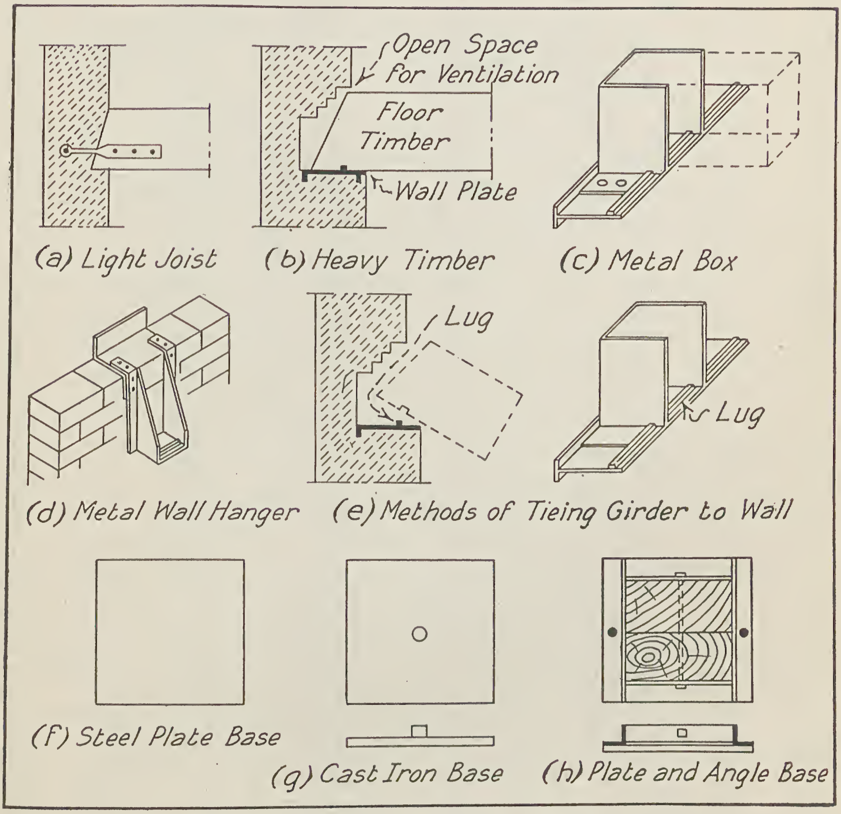



Fig. 79. Wall Supports, Anchors, and Column Bases

**Column Bases.** — Wood columns should not rest directly on masonry footings for moisture may be transferred from the footings to the column causing the end of the column to rot. Column bases are used. They may be steel plates as shown in Fig. 79*f*; cast-iron bases as shown in Fig. 79*g*; or steel bases consisting of a plate and angles riveted together as shown in Fig. 79*h*. Column bases have the additional function of distributing the column load over a larger area on the footing. See also Figs. 85 and 86.

**Frame Construction.** — In the construction of frame houses, and other small frame buildings, the braced frame, the balloon frame, or the plat-

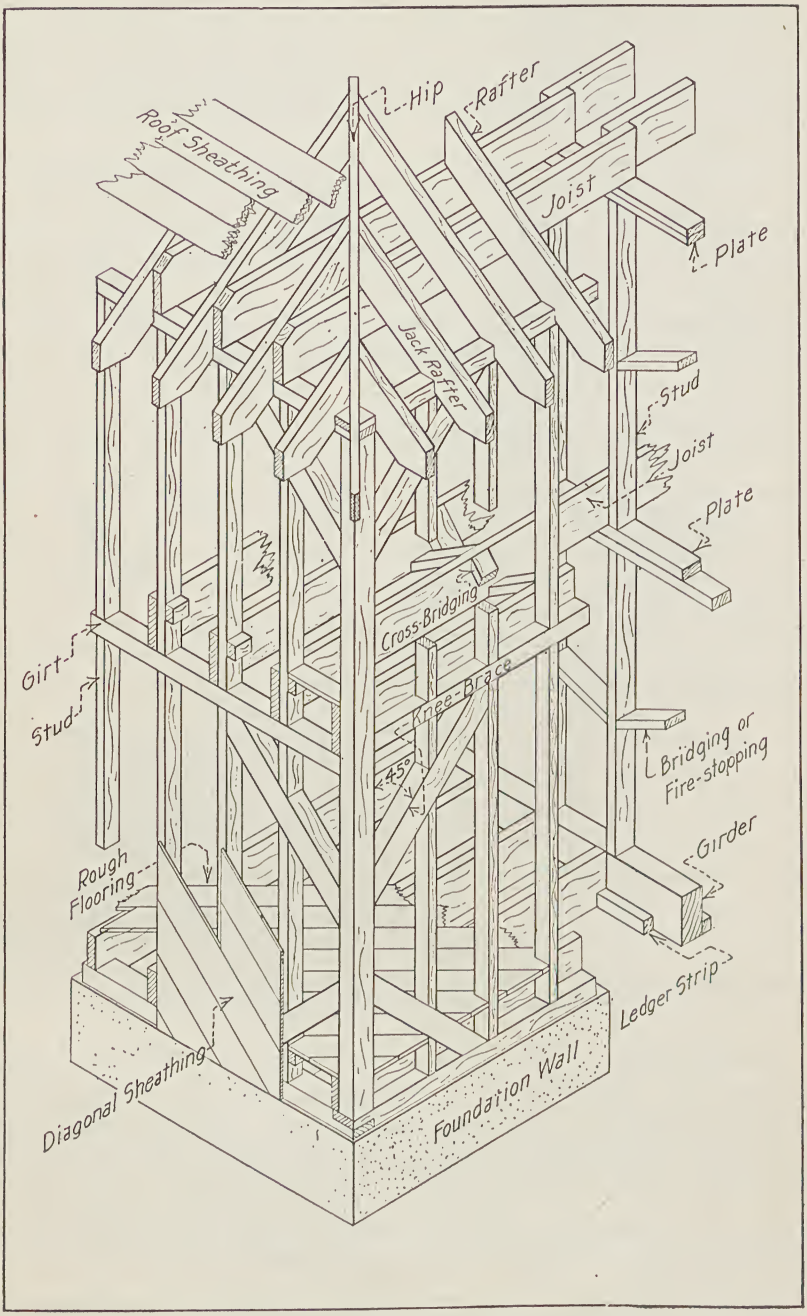



Fig. 80. Braced Frame Construction

form frame may be used. It is not considered good practice to make such buildings over three stories high.

The *braced frame* is illustrated in Fig. 80 and consists of heavy sills, corner posts, plates, and girts which are framed together and given lateral rigidity by heavy *knee-braces* at the corners, in the plane of the walls. The studs are 2 × 4 in. or 2 × 6 in., and usually extend one story, where they frame into the *girt*. The floor joists are 2 in. thick, and vary in depth from 8 to 12 in. Above the first floor, the joists rest on the girts. The rafters are 2 × 6 in. or 2 × 8 in. and are notched to secure bearing on the plate at the top of the studs. *Cross-bridging* spaced not over 8 ft. center to center is used to stiffen the floor and distribute concentrated loads over several joists. The *wall sheathing* may be placed diagonally or horizontally. The sub-floors are always placed diagonally. The partition studs in the second story do not rest on the sub-floor but pass down through the floor and rest on the top plate of the first-story studs. The reasons for this construction are given in Article 28. The figure shows a hip roof but the gable roof as shown in Fig. 81 may be used.

The *balloon frame,* illustrated in Fig. 81, does not have the heavy corner posts, girts, etc., used in the braced frame, the studs are 2 × 4 in. or 2 × 6 in., continuous for two stories. The floor joists are 2 in. thick and from 8 to 12 in. deep. The ends of the floor joists above the first floor are carried on a *ribbon* or *ledger board* which may be as light as 1 × 6 in. but it is preferably 2 × 6 in. This ribbon should be notched into the studding. Cross-bridging is used as in the braced frame. The rafters are notched so as to secure bearing on the plate at the top of the studs. The partition studs in the second story do not rest on the sub-floor but on the top plate of the first-story studs. See Article 28. The balloon frame is used much more than the braced frame, on account of the smaller amount of labor involved. The figure shows the type of framing for a gable roof, but a hip roof as shown in Fig. 80 may be used.

The braced frame and the balloon frame have not been so standardized that there are definite distinctions between the two types in all essential features. The braced frame was so named because of the heavy corner braces which extended diagonally from the heavy girt to the corner posts but it is considered good practice to use 2 × 4-in. braces cut in between the studs. The corner posts of the braced frame should probably be dimension timbers such as 4 × 4 in. or 6 × 6 in. but it is acceptable construction to build these posts up of 2-in. material as in the balloon frame. The balloon frame is often corner braced just as substantially as the braced frame. Either type may have diagonal or horizontal sheathing. There is always an essential difference, however; the outside wall studs of the braced frame extend through one story only and frame

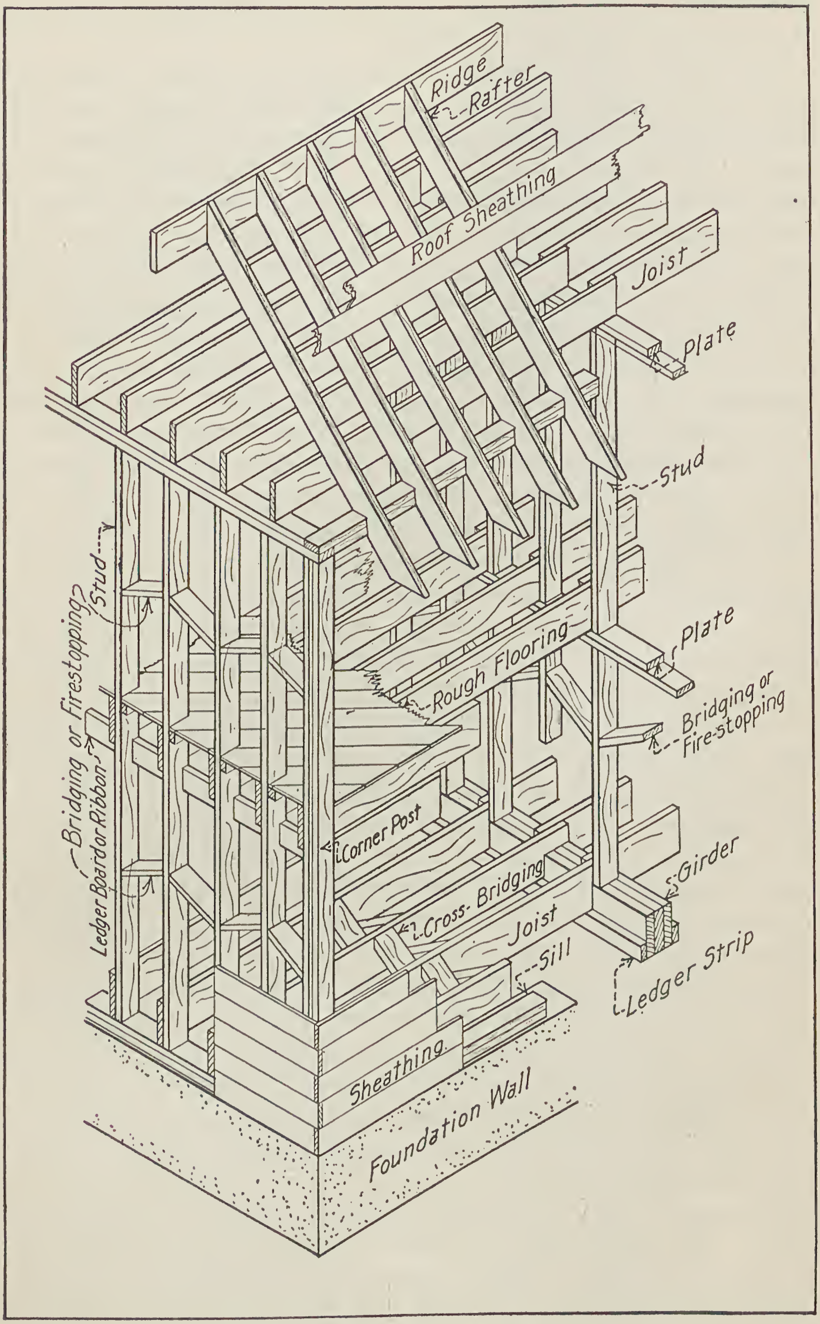



FIG. 81. Balloon Frame Construction

into a heavy girt on which the second-floor joists rest, while the outside wall studs of the balloon frame extend through two stories and the second-floor joists are supported on a light member called a ribbon or ledger board which is notched into the studs about an inch.

In both types of construction all openings, on the inside of walls, partitions and floors, which would permit fire to pass from one part of the building to another should be fire-stopped with some incombustible material. Lath and plaster surfaces are not considered effective fire-stops. The spaces between joists and over the top plate of walls and partitions should be fire-stopped. Solid bridging should be provided between the studs at their mid-height to obstruct the upward passage of fire between the studs and behind the plaster. See Fig. 61.

The *platform frame* is illustrated in Fig. 61 and explained in Article 28.

The braced frame is sometimes called the *drop-girt frame* and the platform frame is sometimes called the *western frame.*

For a discussion of frame walls and partitions see Article 28.

**Ordinary Construction.** — In ordinary construction the walls are of masonry, the interior framing is the same as in the braced frame or balloon frame, but metal beams and columns are sometimes used in parts of the building. See the definition of ordinary construction under Classification of Buildings in Article 2.

A typical cross-section of a two-story dwelling of ordinary construction with brick walls is shown in Fig. 82 and of a two-story business building of ordinary construction with brick walls in Fig. 83. These buildings illustrate the principles of construction which have been explained under the appropriate headings. Some of the more important features are:

1. The outside walls in the dwelling house are 8 in. thick for the second story and 12 in. thick for the first story and basement which corresponds to the usual practice. The recommendations of the Building Code Committee of the Department of Commerce would permit an 8-in. wall to be used for the first story as well as the second story if the allowable unit stresses are not exceeded.

The outside walls of the business building are 12 in. thick for the first and second stories and 16 in. thick for the basement as required.

In both buildings where the walls change in thickness, the thicker wall is extended to the tops of the floor joists.

2. The story heights are low enough in all cases so that the walls receive the required lateral support.

3. On the business building the parapet wall satisfies the minimum height requirement of 32 in. and the maximum height requirement of not over four times its thickness. It satisfies the minimum thickness requirement of 12 in. and the requirement that it be as thick as the wall

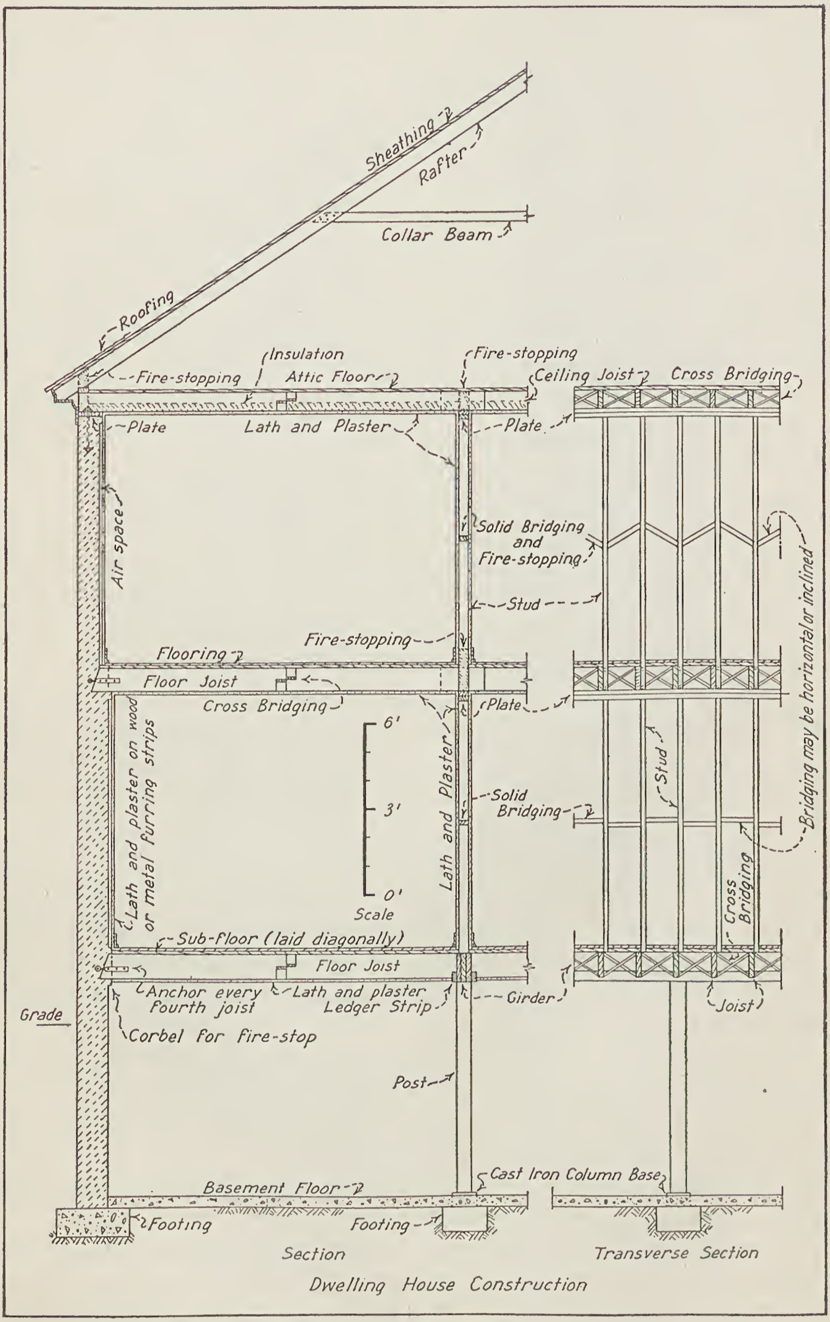



FIG. 82. Ordinary Construction for Dwelling Houses

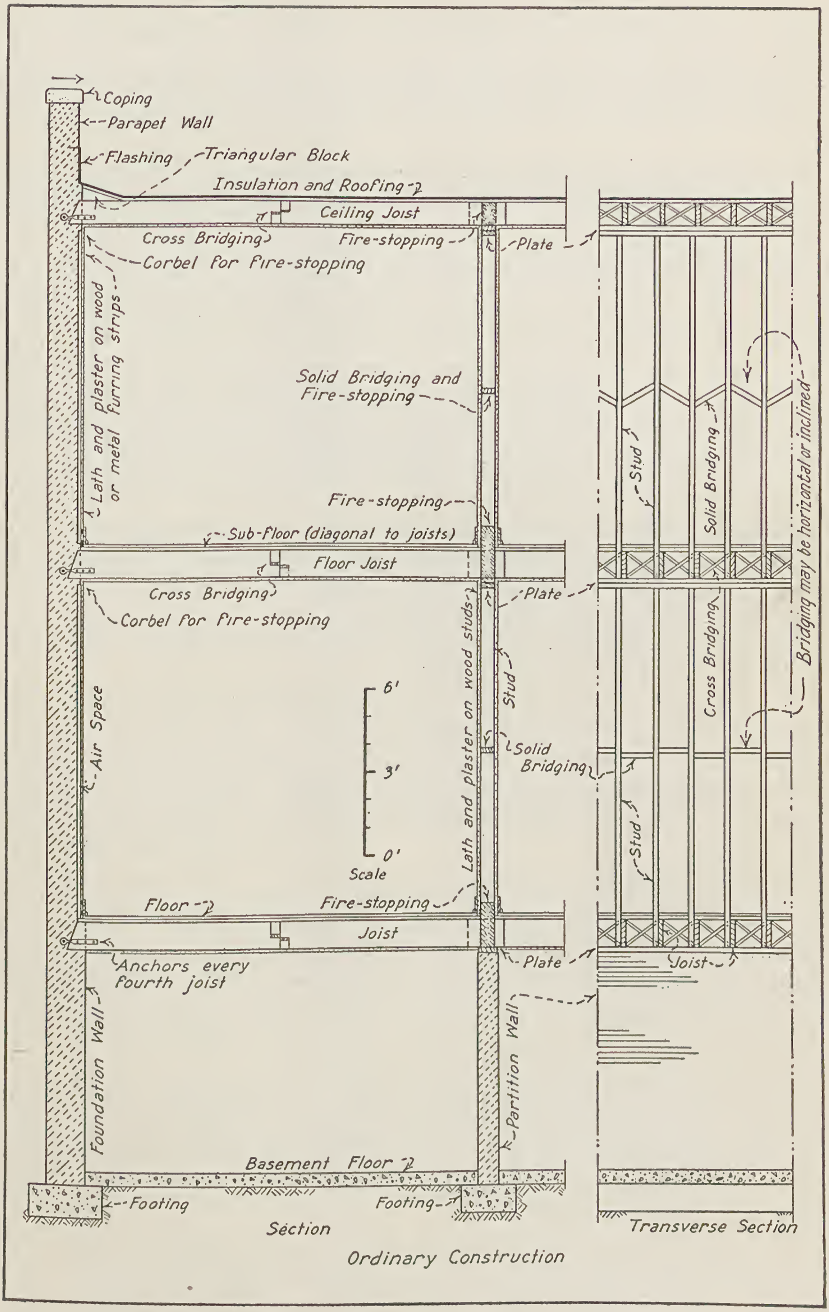



Fig. 83. Ordinary Construction for Light Commercial Buildings

below. It has the desirable feature of a coping which drains toward the roof.

4. The outside walls in both buildings are furred and fire-stops are provided at the floors to cut off the air space behind the furring at each floor.

5. A fire-stop is provided to cut off the cornice on the dwelling house.

6. The bearing wall in the basement is 8 in. thick, which satisfies the recommendations.

7. The studs of the second-story partitions in both buildings bear on the top plate of the stud partition below. This is to reduce settlement due to side shrinkage. This type of construction is greatly superior to that which rests the studs on a sole plate placed on top of the sub-floor.

8. Fire-stops are provided between the studs where they pass through the second floor and between the joists over the plate at the attic floor.

9. Solid bridging is provided at the mid-height of all stud partitions. This bridging stiffens the studs and acts as a fire-stop. The horizontal bridging is staggered to facilitate nailing. In some cases horizontal bridging is shown and in others inclined bridging. The latter gives more lateral resistance to the partition as a whole.

10. The top plates of all stud partitions are doubled and are made of the same size material as the studs.

11. The posts in the basement of the dwelling house bear on independent footings and not on the basement floor. They rest on cast-iron plates which prevent the transmission of moisture from the ground through the footing and into the end of the post. This avoids the danger of rotting. It is sometimes required that the top of this plate be 3 in. above the floor.

12. The floor joists bear 4 in. on masonry walls. The ends which bear on the walls are beveled so that they will release in case of fire.

13. The joists are anchored to the masonry walls by metal anchors placed near the bottom of the joists and located on every fourth joist.

14. Cross-bridging is provided between all joists and since the spans are all less than 16 ft. only one row is required.

15. One end of the first-floor joists in the dwelling house is notched to rest on a ledger strip spiked to the side of the built-up girder. The joists are toe-nailed into the girder. The settlement due to side shrinkage is much less using this type of construction than it would be if the joists rested on top of the girder.

16. Diagonal sub-floors are provided in both buildings. These are much superior to the sub-floor placed at right angles to the floor. The diagonal floors facilitate the laying of the finished floor which should always be laid at right angles to the joists.

17. Solid sheathing is provided on the roof of the dwelling.

18. Insulation is provided above the ceiling of the second story. This makes the dead air space commonly provided under flat roofs unnecessary.

19. An attic floor is provided in the dwelling for convenience, insulation, and to increase the fire resistance.

**Slow-burning or Mill Construction.** — Slow-burning or mill construction as defined in Article 2 has the following essential characteristics:[1]

(*a*) Outside walls of masonry.

(*b*) Heavy timber interior framing arranged with smooth flat surfaces and a minimum number of corners.

(*c*) No concealed spaces which cannot be readily reached in case of fire.

(*d*) Separation of building into units by incombustible walls and partitions provided with doors which will automatically close in case of fire.

(*e*) Separation of floors by enclosing stairways and elevator shafts in fireproof towers or if this is not possible, by encasing them.

(*f*) Avoiding openings in floors for the passage of belts, etc., or by protecting such openings by automatic hatchways or otherwise so as to prevent the passage of fire and water from floor to floor.

(*g*) The installation of an automatic sprinkler system is desirable.

(*h*) The waterproofing of floors and providing drainage so that water will not leak through to the floor below.

(*i*) Protection of ceilings over highly inflammable stocks with a fire-retardant material.

The National Fire Protection Association has adopted the term slow-burning, heavy timber construction for buildings of this class and divides such buildings into three types:

*Girder Type.* — This type includes buildings with floors of heavy planks laid flat upon large timber girders which are spaced not less than 8 ft. on centers and supported by wood posts or columns at intervals of not less than 12 ft. This type is commonly called *standard mill construction.*

*Beam and Girder Type.* — This type includes buildings with floors of heavy planks laid flat upon large timber beams spaced not less than 4 ft. on center and supported by large timber girders and wood posts or columns spaced according to sound engineering practice. This type is commonly called *semi-mill construction.*

*Laminated Type.* — This type includes buildings with floors of heavy planks laid on edge upon large girders spaced not less than 12 ft. on center and supported by wood posts or columns at intervals preferably not less than 16 ft. This type is commonly called *mill construction with laminated floors.*

[1] Arranged from publications of National Lumber Manufacturers' Association.

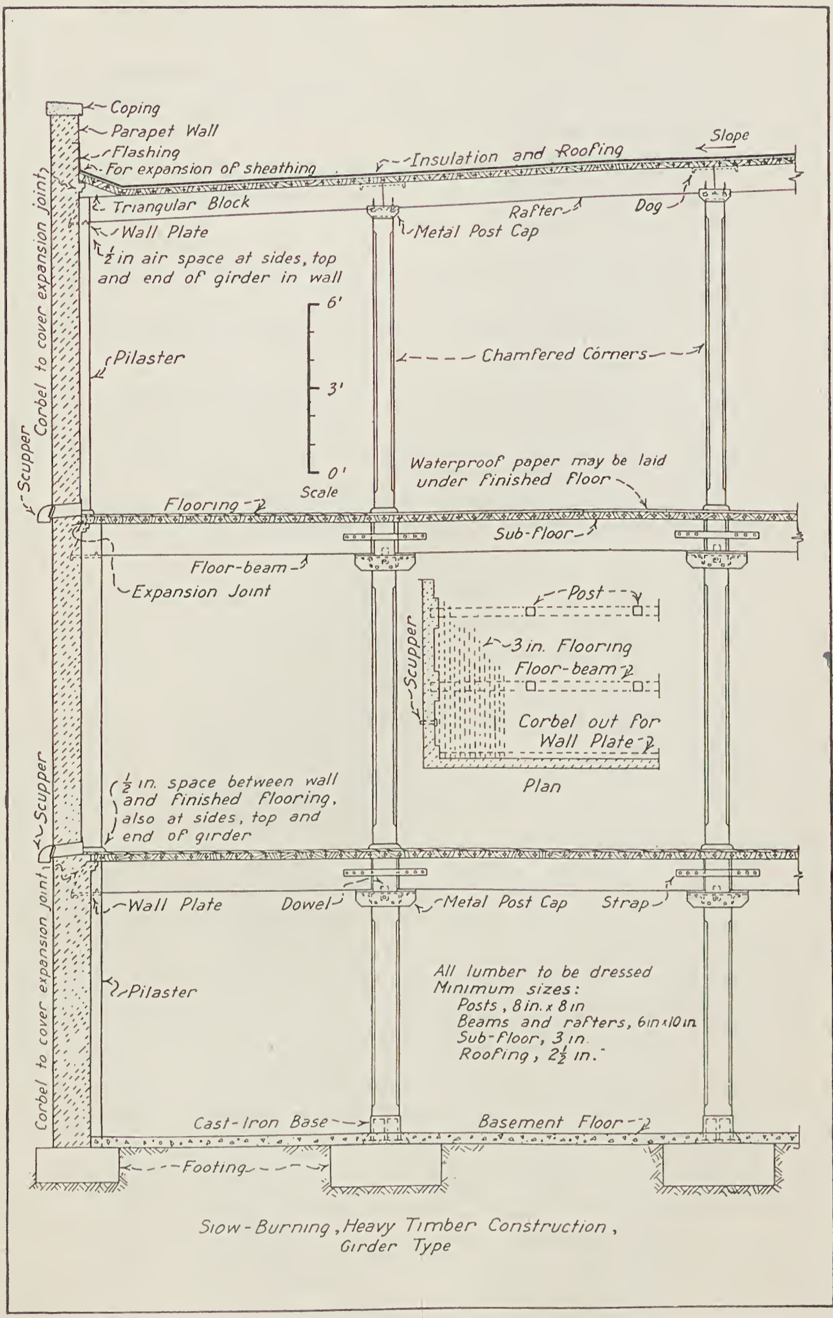



FIG. 84. Slow-burning, Heavy Timber Construction, Girder Type

The substitution of protected steel or reinforced-concrete framing for portions of the structure is not considered as altering the type. The floors of all of the above types are provided with a top floor to take the wear and give a finished surface.

A typical cross-section of a slow-burning, heavy timber construction, girder type building is shown in Fig. 84.[1] The essential features of this type of construction are:

1. Heavy masonry walls with 3-ft. parapet. Coping slopes draining to roof.
2. Heavy timber girders with minimum size of 6 in. × 10 in.
3. Wall end of girder ventilated on sides and top to prevent dry rot and resting on metal wall plate which anchors girder but would release it if it burned in two and fell.
4. Column end of girders supported on columns by metal post caps which permit columns of story above to pass the end of the girders.
5. Lines of girders tied across columns by metal straps except the roof girders which are tied by metal dogs.
6. Heavy timber columns with minimum size of 8 in. × 8 in.
7. Corners of columns chamfered.
8. Columns of each story pass ends of girders and rest on column below. Columns held in line by dowels in caps.
9. Bottom of columns rests on cast-iron base which distributes load on footings and prevents ground moisture from entering end of column and causing rot. End of column is raised well above the basement floor.
10. Heavy wood sub-floor with minimum thickness of 3 in.
11. Floor planks joined by a loose tongue or spline which is preferable to matching for heavy floor. Heavy roof sheathing with a minimum thickness of $2\frac{1}{2}$ in.
12. Expansion joint left between wall and sub-flooring and sheathing and between wall and finished flooring to permit swelling without pushing wall out. Expansion joint covered on lower side by corbel in wall and on upper side by molding nailed to wall but not to the floor.
13. Roof insulated to reduce heat losses in cold weather and to make building cooler in hot weather.
14. Finished floor placed on sub-floor to take wear and improve appearance.
15. Waterproof paper placed under finished floor if desired.
16. Scuppers provided in outside walls and in interior where necessary to drain floor of water from automatic sprinklers or fire hose in case of fire.
17. All lumber is dressed to increase its fire resistance. Oil paint or varnish not used.

[1] Arranged from publications of the National Lumber Manufacturers' Association.

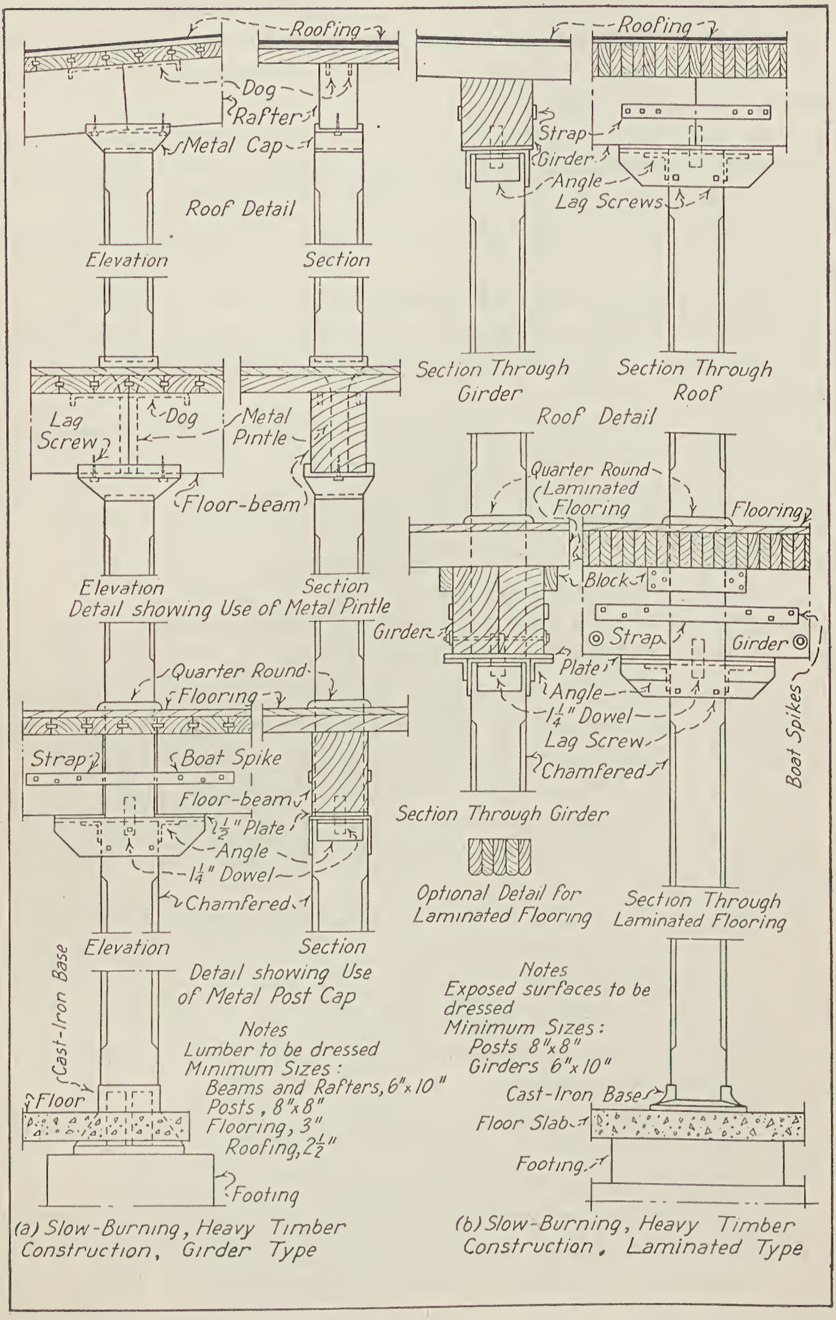



Fig. 85. Details of Slow-burning Construction

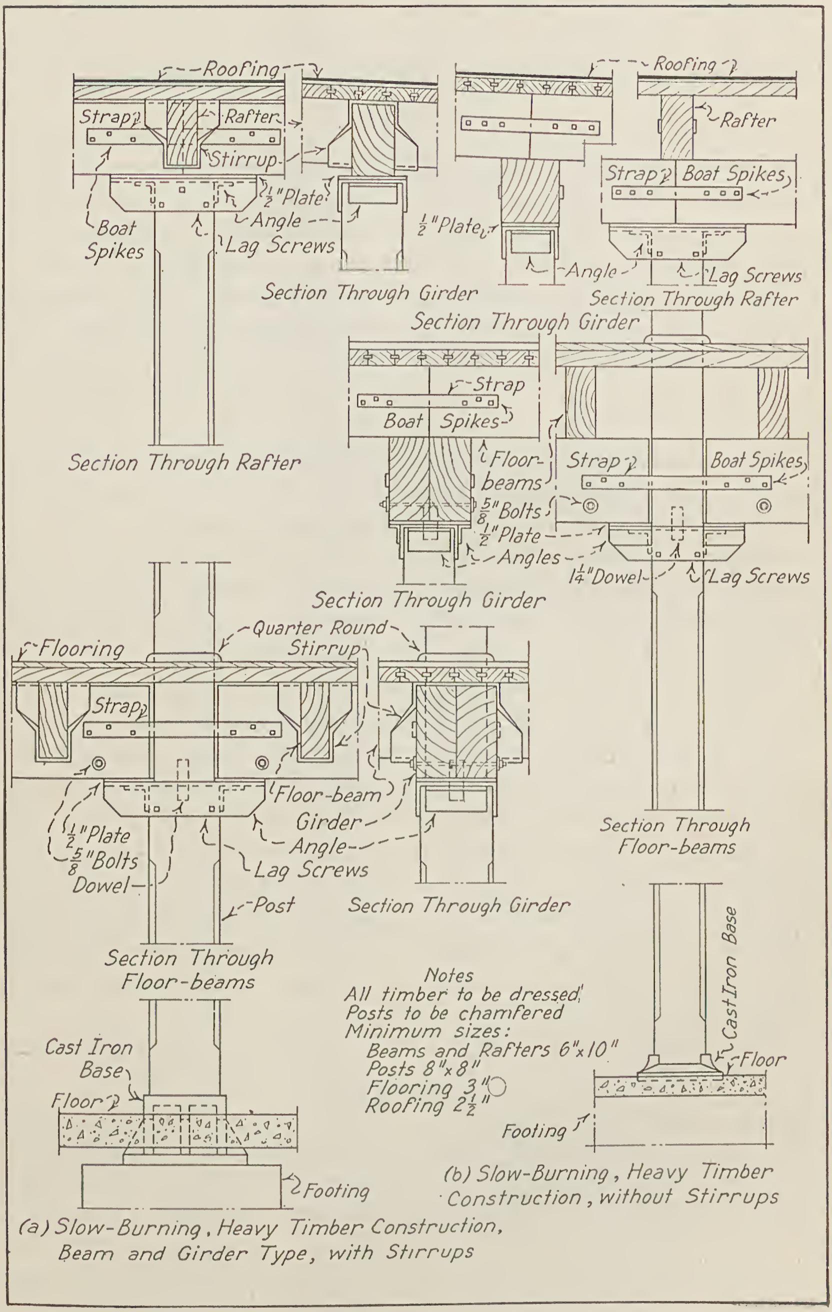



FIG. 86. Details of Slow-burning Construction

The details used in slow-burning, heavy timber construction of the girder type and of the laminated type are shown in Fig. 85.[1] In addition to the features mentioned in the discussion of Fig. 84 the following should be noted:

1. The cast-iron post cap and pintle. The function of the pintle is to carry the column load to the column below without resting the column on the girders. If the columns rested on the girders and the girders burned in two at any floor the columns above that floor would be pulled over and a general failure would result. Pintles are not often used.

2. The laminated floor consisting of planks placed on edge and spiked together makes an excellent floor and makes longer spans possible. The corners of these planks are often chamfered. To permit expansion and contraction, the laminated floor is not fastened to the girders on which it rests.

3. Due to the longer spans of the laminated floors, heavier floor girders may be required in this type of construction. A girder consisting of two timbers placed side by side and bolted together is shown.

4. Blocks are provided to carry the ends of the flooring over the gap between the ends of the girders framing into the two sides of the columns when the built-up cap is used. These are not necessary when the pintle is used because the ends of the girders then come together.

5. Built-up caps are fastened to the columns with lag screws. Cast-iron caps are fastened to the girders with lag screws.

The details used in slow-burning, heavy timber construction of the beam and girder type are shown in Fig. 86.[1] Many of the details mentioned in discussing Fig. 85 apply also to this type of construction. The construction feature peculiar to this type is the use of beams to carry the floor planks. These beams are spaced from 4 to 10 ft. apart and are supported by the girders either by resting their ends on top of the girders or by supporting the ends in metal stirrups. The latter method gives more headroom and is more compact but the metal stirrups are a point of weakness in case of fire.

## REFERENCES

Publications of the National Lumber Manufacturers' Association; Timber Framing, by Henry D. Dewell, Dewey Publishing Co.; Architectural Construction, Vol. 2, Part 1, by Voss and Varney, John Wiley and Sons, Inc.; Structural Details, by H. S. Jacoby, John Wiley & Sons, Inc.; Steel and Timber Structures, by Hool and Kinne, McGraw-Hill Book Co.

[1] Arranged from publications of the National Lumber Manufacturers' Association.

# CHAPTER VII

# STEEL CONSTRUCTION

## ARTICLE 35. STEEL COLUMNS

**Types of Columns.** — Structural steel columns may consist of a single piece, such as the H-column, or may be built up of structural shapes to form a great variety of sections as shown in Fig. 87*a* to *o*.

The shapes which are to be used to form a given section are riveted together at frequent intervals so that the entire section will act as a unit.

The H-section shown in Fig. 87*a* is very extensively used. The Bethlehem Steel Company rolls H-sections with nominal depths varying from 6 in. to 16 in. by 2-in. increments; areas varying from 5.89 sq. in. to 125.72 sq. in. and weights varying from 20.0 lb. per ft. of length to 427.0 lb. For each nominal depth there are sections of several weights and areas. The change in section is made by changing the thickness of the web and the flanges, as shown in Fig. 88*a*. The clear distance between the flanges is kept constant, so that any change in flange thickness changes the depth. For this reason the actual depth differs from the nominal depth used in designating the section. The flanges taper slightly, being thinner at the extreme edge than they are near the web. The flange thickness for the group of sections designated as 16 in. varies from about 1 in. to about 3 in. and the web thickness from 0.72 in. to 1.94 in. Due to the variation in the flange thickness the depth of this group of sections varies from $14\frac{1}{2}$ in. to $18\frac{7}{16}$ in. The flanges of the 6-in. section vary in thickness from $\frac{3}{8}$ in. to $\frac{3}{4}$ in., the web from $\frac{1}{4}$ in. to $\frac{1}{2}$ in. and the depth from 6 in. to $6\frac{3}{4}$ in. Corresponding ranges in dimensions exist in the other sections.

A comparison of the maximum and minimum sections of the 14-in. Bethlehem H-sections and the relation between these sections is shown in Fig. 88*a*. The clear distance inside of the flanges is constant for all sections in a given group, the area being increased by increasing the flange thickness by additions to the outside, by increasing the flange width and by increasing the web thickness. There are 39 sections in the 14-in. group, varying in weight from 43 lb. per ft. to 298 lb. per ft. and in area from 12.58 sq. in. to 87.63 sq. in. The slope of the inside of the flanges is 1 in 50.

The Carnegie Steel Company rolls H-sections of two types: the variable-depth type and the constant-depth type. In the *variable-*

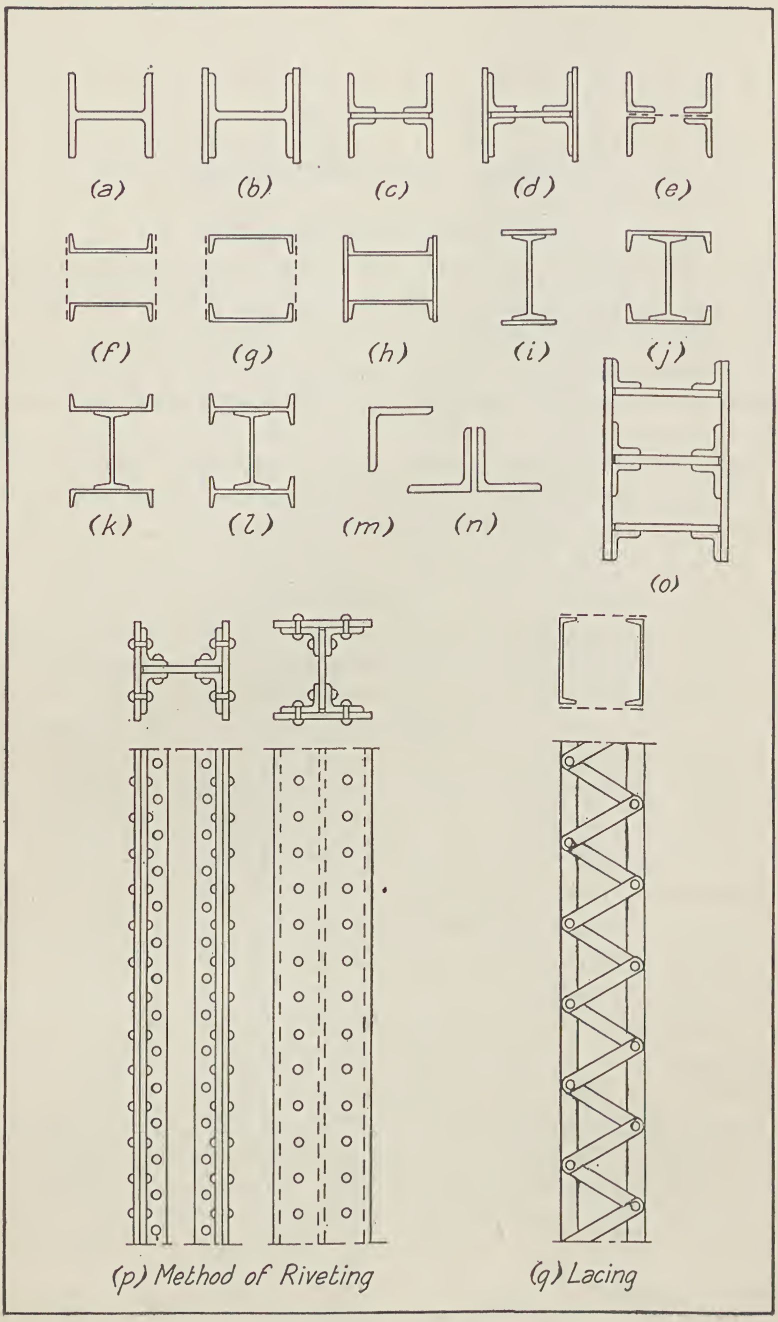



FIG. 87. Types of Steel Columns

*depth type* the clear distance between flanges is constant, as shown in Fig. 88*a*, for all of the sections in a group, the increase in area being made in the same manner as with the Bethlehem H-section. In the *constant-depth type* the distance back to back of the flanges is constant, the increases in area being made by increasing the flange thickness by additions to the inside, by increasing the flange width, and by increasing the web thickness.

The variable-depth Carnegie sections are available in three groups with nominal depths varying from 8 in. to 14 in.; areas varying from 9.10 sq. in. to 124.99 sq. in. and weights varying from 31 lb. per ft. to 425 lb. per ft. A comparison of the maximum and minimum sections of 14-in. nominal depth is shown in Fig. 88*a*.

The constant-depth Carnegie sections are available in 10-in. and 12-in. depths with areas varying from 9.11 sq. in. to 67.64 sq. in. and weights varying from 31 lb. per ft. to 230 lb. per ft. A comparison of the maximum and minimum sections of the 12-in. depth series is shown in Fig. 88*a*. The flanges do not taper as do those of the Bethlehem sections. Using the 10-in. series the columns of an ordinary 12-story building may all be made of the same depth and do not require fillers at the splices. An ordinary 18-story building may be constructed with the columns of the lower floors composed of sections for the 12-in. series and those above of the 10-in. series.[1] The constant depth of the sections in each series simplifies the shop work considerably.

A light 6-in. H-section series is rolled by the Bethlehem Steel Company for use in buildings carrying light loads. The minimum section has a web thickness of $\frac{1}{4}$ in. and a flange thickness of $\frac{1}{4}$ in., which is the minimum thickness of metal permitted by many building codes. The area of this section is 4.61 sq. in. and its weight 15.5 lb. per foot. Two heavier sections in the same series are available. Columns in this series are classed as *stanchions* by the Bethlehem Steel Company to distinguish them from the ordinary column sections.

The Carnegie Steel Company rolls 4, 5, 6, and 8-in. H-beams of special design and suitable for light loads.

The size of cross-sections of H-section columns can be increased by riveting one or more plates to the back of each flange as shown in Fig. 87*b*. For thicknesses of metal greater than 1 in., holes must be drilled instead of being punched. Only a few shops are equipped to do this drilling economically. There is a limit to the flange plate area which should be added to the section whose flange thickness does not exceed 1 in. for the web thickness would be relatively too thin for good design. To meet this condition special *column-core* H-sections are rolled by the

[1] Carnegie-Beam Sections, p. 6.

Bethlehem Steel Company and the Carnegie Steel Company. They are available in the 14-in. depth only and have flange thicknesses which are less than 1 in., so can be punched, and web thicknesses which are con-

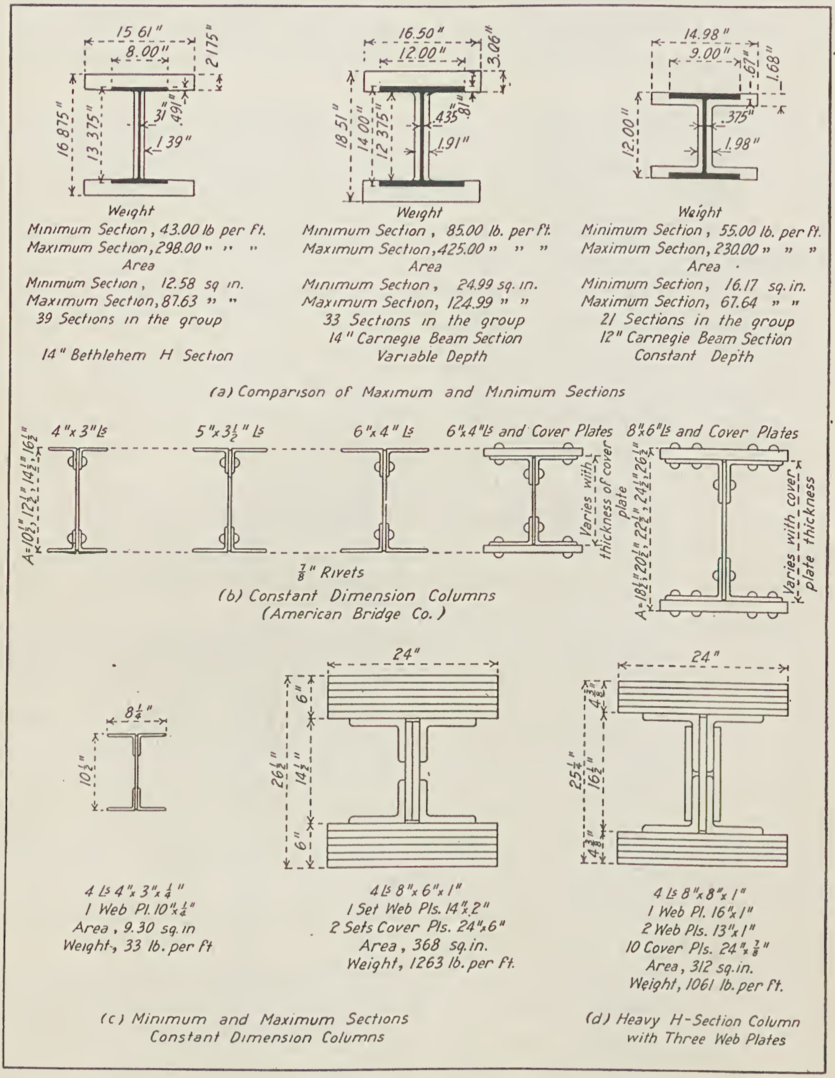



Fig. 88. Types of Steel Columns

siderably greater than those of the ordinary section whose flange thickness is less than 1 in.

The built-up H-sections, shown in Fig. 87c, called plate-and-angle columns, are probably used more extensively than any other form of

*Dilks Construction Co., Builders* *D. H. Burnham & Co., Architects*

THE BANKERS BUILDING CHICAGO, ILL.

built-up column. A large assortment of sections can be built up from a limited stock of plates and angles. The section is increased by adding flange plates as shown in Fig. 87*d* in the same manner as with the rolled H-section columns. Beam and girder connections are easily made to this type of column. The distance back to back of angles is usually made $\frac{1}{2}$ in. greater than the width of the web plate so that, if the width of the web plate overruns, there will be no difficulty in riveting flange plates, beam connections, etc. to the backs of the angles.

A type of built-up column which corresponds to the constant depth H-section has been devised by the American Bridge Company and is illustrated in Fig. 88*b*. The section is a built H with or without flange plates. The overall depth including flange plates is kept constant for all sections in each series. There are nine series beginning with a depth of $10\frac{1}{2}$ in. and extending to $26\frac{1}{2}$ in. by increments of 2 in. The sizes of angles and other information are given in Fig. 88. The minimum section consists of 4 angles $4 \times 3 \times \frac{1}{4}$ in. with a $10 \times \frac{1}{4}$-in. web plate. It has an area of 9.3 sq. in. and weighs 33 lb. per ft. The maximum section consists of 4 angles $8 \times 6 \times 1$ in., the thicknesses which are greater than 1 in., usually being made up of $\frac{7}{8}$-in. or 1-in. plates so that the holes can be punched. This section has an area of 368 sq. in. and weighs 1263 lb. per ft. A comparison of the maximum and minimum sections of the American Bridge Company *constant-dimension columns* is shown in Fig. 88*c*.

The following information concerning constant-dimension columns is quoted from the Structural Engineers' Handbook by M. S. Ketchum:

Constant-dimension columns have the advantages (1) that their extreme dimensions are known in advance; (2) that wall columns can be spaced at a minimum distance from the outside limits of the building giving uniformity to the construction; (3) adjacent columns having different loads can have the same outside dimensions, thus reducing the number of column sizes in the building.

For high buildings where the lower columns are large, the sizes can be reduced for the upper stories, but in general for office buildings, hotels and similar structures, after a 14-in. or a 16-in. column is reached, the size should be maintained with varying sections to the top of the building.

No column should be smaller than 10 in. and preferably not smaller than 12 in. Where framed connections and wind bracing are used, care must be taken to select columns with sufficient clearance to permit the driving of long rivets.

For office buildings of the usual type, about 25 stories high, the selection of columns preferably should be either 16-in. columns throughout, or 16 in. for the first two lengths, and 14 in. above. If the wind moment or special loadings influence the selection, the 18-in. columns should be used for the first two lengths and 16 in. above.

For hotels about 15 stories high, the selection of columns preferably should be

14 in. throughout or if special loading or wind stresses are involved, 16 in. for the first two lengths and 14 in. above. For apartment houses of the usual type, about 12 stories high, 10-in. columns generally can be used throughout.

A heavy H-section column making use of three web plates is shown in Fig. 88*d*.[1]

A column consisting of four angles held together by *lacing bars* as shown in Fig. 87*e* was quite extensively used a few years ago in certain classes of construction but its use has been practically abandoned at the present time. The lacing bars are indicated by the broken line. An elevation of a channel column with lacing bars is shown in Fig. 87*q*.

Columns may be constructed of two channels with flanges turned out and held together by lacing bars as shown in Fig. 87*f*, or the flanges may be turned in as shown in Fig. 87*g*. Two channels with flanges turned out may be held together by two plates as shown in Fig. 87*h*, but plates cannot be used to fasten together two channels with flanges turned in because the rivets could not be driven without great difficulty.

Plates may be riveted to the flanges of I-beams as shown in Fig. 87*i*. Channels with flanges turned in or out as shown in Figs. 87*j* and 87*k* or I-beams as shown in Fig. 87*l* may also be riveted to the flanges or I-beams. Under certain conditions an I-beam may be used as a column but such a column is not usually economical.

A single angle as shown in Fig. 87*m*, or two angles fastened together at intervals may be used as shown in Fig. 87*n*. The chief use of such sections acting as columns is for the compression members of trusses.

Columns with three web plates as shown in Fig. 87*o* are sometimes used.

Only a few of the more simple column sections have been mentioned but a great variety of sections may be built up to suit special needs.

The method of riveting the various parts of built-up columns together is illustrated in Fig. 87*p*.

## ARTICLE 36. STEEL GIRDERS, BEAMS AND JOISTS

Girders, beams, and joists are all members which are subjected to bending stresses as explained in Article 23. In general, if a distinction is made between the terms beam and girder, the heavier members are called girders. Since there is no definite distinction between the two terms the term beam will usually be used throughout this article. Joists will be considered separately.

**I-Beams.** — Steel beams may consist of a single section rolled to the desired shape or several shapes may be assembled to form built-up

[1] Engineering and Contracting, Vol. LXVII, p. 362.

sections. The most common form of rolled steel beam has an I-shaped cross-section as shown in Fig. 89*a* and is called an *I-beam.* The wide parts of the section at the top and bottom are called the *flanges* and the

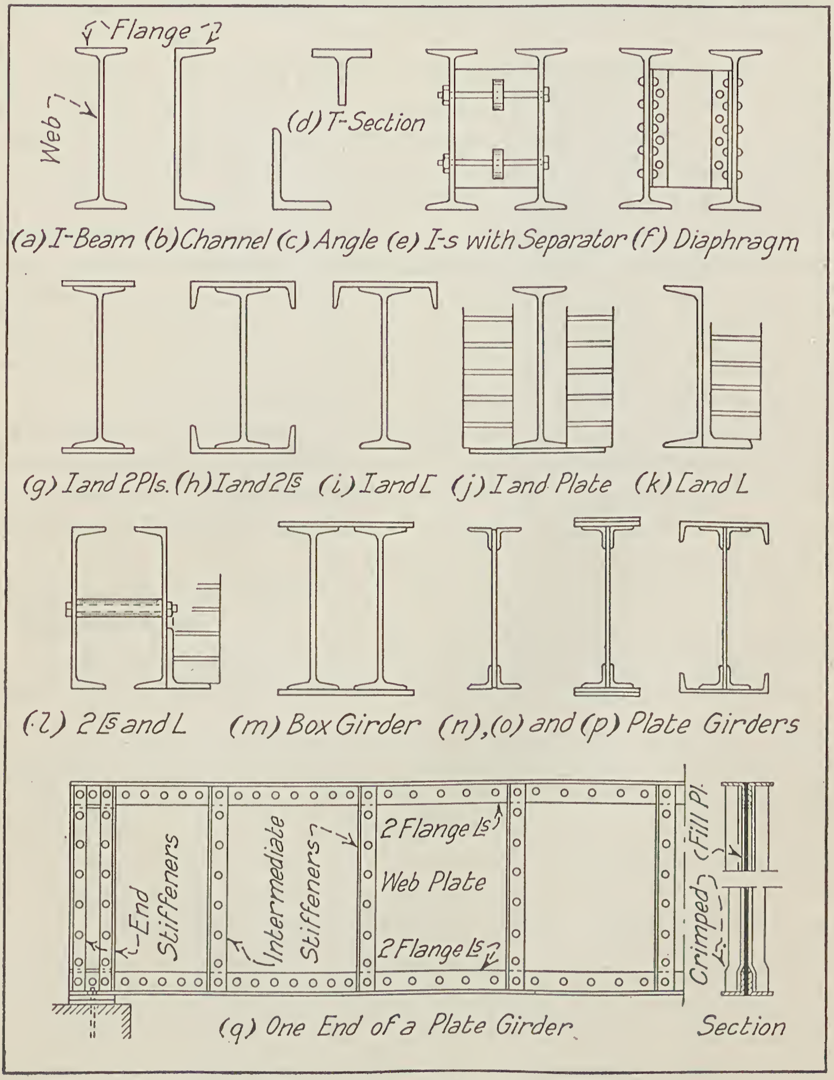



Fig. 89. Types of Steel Beams and Girders

narrow connecting portion is called the *web.* This type of beam may be divided into three general classes: American Standard Sections, which may be rolled by any manufacturer; Bethlehem Sections, which are rolled only by the Bethlehem Steel Company; and Carnegie Beam

Sections, which are rolled only by the Carnegie Steel Company or associated companies.

**Standard I-Beams.** — The American Standard Sections are available in sizes varying from 3 in. to 24 in. in depth. For each depth, sections of various weights are rolled, the increase in section above the minimum section being made by spreading the rolls so as to give a thicker web and correspondingly wider flanges as shown in Fig. 90*a*. The thickness of the flanges is not changed. Since most of the bending strength of an

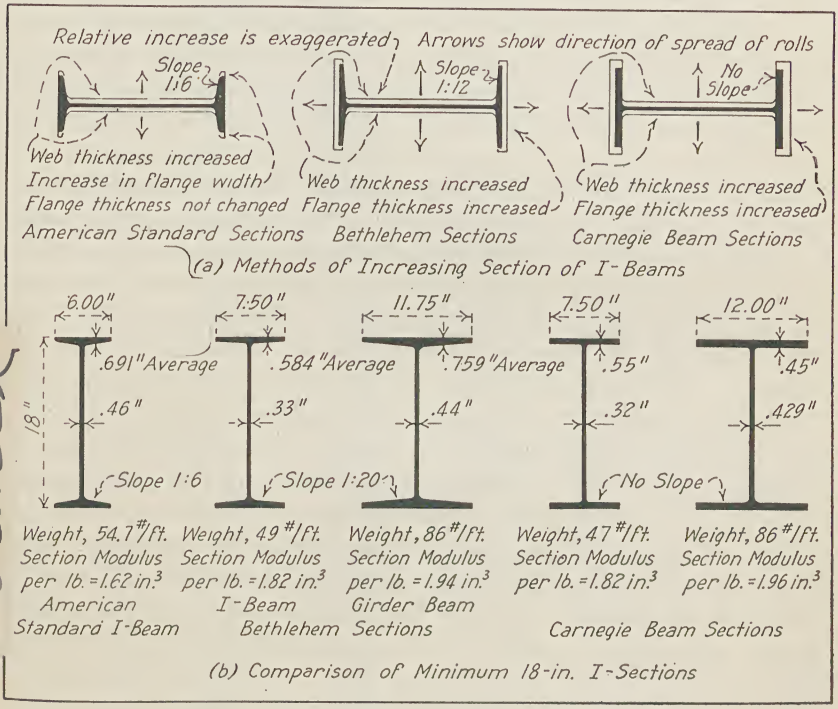



FIG. 90. Steel I-beams

I-beam is due to the flanges and since the spreading of the rolls adds much more weight proportionately to the web than it does to the flanges the sections which are heavier than the minimum, for any depth, are not as efficient in resisting bending as the minimum section. For this reason the minimum sections are more in demand than the other section and are more easily obtainable. The flanges of the sections in this group increase in thickness from the edge toward the web with a slope of 1 to 6, as may be seen from the figure. The depths and minimum weights for the American Standard Section vary from the 3-in. section weighing 5.7 lb. per ft. to the 24-in. section weighing 79.9 lb. per ft. The maximum

24-in. section weighs 120 lb. per ft. The strength of beam sections is measured by their ability to resist bending. The property of the section which is a measure of the bending resistance is the *section modulus.* The section modulus of the minimum 3-in. section is 1.7 in.$^3$ and that of the minimum 24-in. section is 173.9 in.$^3$. The section modulus of the maximum 24-in. section is 250.9 in.$^3$.

**Bethlehem Sections.** — Bethlehem sections which are used for beams are of two types: *girder beams* and *I-beams.* Both sections have an I-shaped cross-section but the flanges of the girder beams are much wider and thicker than the flanges of the I-beams and their webs are thicker. For a given depth, the girder beams will carry a considerably greater load than the I-beams but the carrying capacity per pound of material is only slightly greater. The flanges of both types are thinner at the edges than at the center, the slope of the inside of the flanges being 1 in 12. The depths for both types vary from 8 in. to 36 in. For each depth there are about four sections of different weights. The increase in section above the minimum section is made by increasing the thickness of the web by spreading the horizontal rolls, and the thickness of the flanges by spreading the vertical rolls as shown in Fig. 90*a*. The increase in the flange section is about the same proportionately as the increase in the web section, so all of the sections of a given depth have about the same efficiency in load carrying capacity. The increase in flange thickness is made by adding to the outside of the flange, so the depth of the beam is slightly increased. The difference in depth between the maximum and minimum sections for a given nominal depth is $\frac{3}{8}$ in. for the heaviest sections. The usual stock sizes include one section for each depth. This is the section of which the actual depth equals the nominal depth for that group of sections. It is not the minimum section. The depths, weights, and sections moduli for the minimum and maximum sections are:

| | *Depth, in.* | *Weight, per ft., in.$^3$* | *Section Modulus, in.$^3$* |
|---|---|---|---|
| Girder Beams, Min. | 8 | 29.5 | 25.6 |
| Max. | 36 | 260.0 | 949.5 |
| I-Beams, Min. | 8 | 17.5 | 14.4 |
| Max. | 36 | 173.0 | 595.0 |

**Carnegie Beam Sections.** — Carnegie beam sections have an I-shaped cross-section. They are not divided into types according to the width of flange with different names to correspond with the Bethlehem sections but are placed under the one designation; from two to seven groups of beams with different flange widths are rolled for each depth. The flanges

on all sections are of uniform thickness thus doing away with the inside taper. The depths vary from 8 in. to 30 in. For each depth and flange width there are several sections. The increase in section above the minimum section is made by increasing the thickness of the web by spreading the horizontal rolls, and of the flanges by spreading the vertical rolls, as shown in Fig. 90*a*. The increases in the flange thickness and the web thickness are proportionate so that all sections of a given depth have about the same efficiency in load carrying capacity. The increase in the flange thickness is made by spreading the vertical rolls, thereby adding to the outside of the flange so the depth of the beam is increased. The minimum section has a depth of 8 in., a flange width of 6.5 in., a weight of 24 lb. per ft. and a section modulus of 21.1 in.$^3$. The maximum section has a depth of 30.78 in. a flange width of 14.22 in., a weight of 240 lb. per ft. and a section modulus of 737.9 in.$^3$.

A comparison of the minimum 18-in. I-sections of the various types is shown in Fig. 90*b*.

Factors which have not been mentioned in the above discussion and which may be of importance in beams with short spans carrying heavy loads, are the resistance to shear and the resistance of the web to buckling. The web of an I-beam carries practically all of the shearing stresses. These factors may make it necessary to use sections with thicker webs than would ordinarily be used. Stiffeners may be required to support the webs of I-beams in the same manner as in the plate girders described later in this article. Beams which are unsupported laterally or which have widely-spaced supports tend to fail by lateral buckling of the compression flange under smaller loads than would cause failure if adequate lateral support is provided. The beams with wide flanges offer more resistance to failure in this manner than do the beams with narrow flanges.

**Channels, Angles, etc.** — Steel channels as shown in Fig. 89*b* are often used for beams where the conditions require that this shape be used or where the loads are so light that channels will be more economical than I-beams. They are commonly used for purlins supporting roofs. The *flanges* and *web* of a channel are designated in the figure.

An angle section may be used for light loads and short spans. Angles are commonly used for lintels supporting face brick and stone over window and door openings.

**Built-up Sections.** — The T-section shown in Fig. 89*d* may be used as a beam when the conditions require that this shape be used. This section is extensively used for rafters supporting gypsum blocks in which case it is inverted to receive the blocks.

Beams may be composed of two or more I-beams placed side by side

and fastened together by *separators* as shown in Fig. 89*e* or by *diaphrams* composed of plates and angles riveted together as shown in Fig. 89*f*.

Plates may be riveted to the flanges of I-beams as shown in Fig. 89*g* to secure greater strength or channels may be used instead of the plates as shown in Fig. 89*h*. In some cases a channel is riveted to the top flange only, as shown in Fig. 89*i* to suit special requirements. A plate may be riveted or welded to the bottom flange of an I-beam to form a lintel for supporting brickwork over a window or door opening as shown in Fig. 89*j*.

Lintels are often formed of an angle riveted or welded to a channel as shown in Fig. 89*k*, the face brick or stone resting on the angle. Another channel may be used with this section, the two parts being held together by separators like those shown in Fig. 89*e* or pieces of pipe may be used for separators as shown in Fig. 89*l*.

Box girders may be formed of two I-beams side by side joined together by flange plates as shown in Fig. 89*m*.

**Plate Girders.** — If I-beams of sufficient strength and of the proper depth are not available, built-up beams composed of four angles and a web plate riveted together as shown in Fig. 89*n* may be used. The strength of such sections may be increased by riveting one or more flange plates to each flange, as shown in Fig. 89*o*, or by riveting channels to the flanges as shown in Fig. 89*p*. Many other types of flanges are used. These built-up sections are called *plate girders*. The webs of plate girders must have a thickness of not less than $\frac{1}{160}$ of the unsupported distance between flanges. If the web is thinner than $\frac{1}{60}$ of the unsupported distance between flanges it is necessary to stiffen it against buckling. This is done by riveting vertical angles to the web as shown in Fig. 89*q*. These angles are called *stiffeners*. They usually are arranged in pairs, one on each side of the web. They should extend the full distance between the insides of the flange angles. It is necessary to provide *fill plates* under the stiffeners and equal in thickness to the flange angles, as shown in the upper part of the section in Fig. 89*q*, or the stiffeners may be bent around the vertical leg of the flange angles as shown in the lower part of the section. This bending process is called *crimping*. Another condition which requires stiffeners occurs when concentrated loads are carried by the flanges of the girder. In this case the ends of the stiffeners should bear tightly against the inside of the flanges. Stiffeners should be placed over the end bearings of girders. Such stiffeners should be on fill plates and should bear against the flange angles. Large shearing stresses may require that stiffeners be used even though the web is thicker than $\frac{1}{60}$ of the unsupported distance between flanges. The spacing of stiffeners is a function of the shear at the section considered but it should never exceed 6 ft.

The flange plates of plate girders should not extend more than 6 in., or more than 12 times the thickness of the thinnest flange plate, beyond the outer row of rivets connecting them to the flange angles.

**Joists.** — Several forms of steel joists are on the market for use in the construction of floors carrying light loads. They are spaced from 12 in. to 30 in. apart and usually carry a thin reinforced-concrete floor slab on their top flanges. They must be securely braced laterally or they will fail by buckling of the top chord or by twisting. The lower side usually carries a metal lath and plaster ceiling for the story below. This protects the light steel members from fire.

Steel joists may be divided into four general types:

(*a*) Rolled I-section joists.
(*b*) Plate girder joists.
(*c*) Strip or sheet-steel joists (metal lumber).
(*d*) Trussed steel joists (bar or rod joists).

Two forms of rolled joists are on the market, the Jones and Laughlin Junior beams and the Bethlehem steel joists. Both of these types are of I-shaped cross-section. The *J and L Junior beams* as shown in Fig. 91*a*, are rolled in depths varying by inches from 6 in. to 12 in. with one section for each depth. These are thin metal sections with thickness varying from a minimum of somewhat less than $\frac{1}{8}$ in. to a maximum of about $\frac{3}{16}$ in. The weight varies from 4.16 lb. per ft. for the 6-in. section to 11.13 lb. per ft. for the 12-in. section. Other properties of these sections are shown in Fig. 91*a*. The end connections are of the same type as used on other steel beams.

The *Bethlehem steel joists*, as shown in Fig. 91*b*, are rolled in depths varying by 2-in. increments from 6 in. to 12 in. with one section for each depth. These sections are designed to meet the requirement that the thickness of metal shall be not less than $\frac{1}{4}$ in., found in many building codes. The thickness of metal in the webs and flanges are in practically $\frac{1}{4}$ in. for all sections. The weights of the sections vary from 11 lb. per ft. for the 6-in. sections to 18.5 lb. per ft. for the 12-in. section. The end connections are of the same type as used on other steel beams.

*Plate girder joists* consist of a built I-section composed of four flange angles and a web plate as shown in Fig. 91*c* joined by electric welds. They are manufactured in depths varying from 6 in. to 14 in. and are constructed of thin metal, the flange angles being $\frac{1}{8}$ in. thick and the web plate varying from $\frac{1}{14}$ in. to $\frac{1}{7}$ in.

*Strip joists* or sheet-steel joists are made from pressed-steel channel sections spot-welded or riveted together in pairs to form an I-section as shown in Fig. 91*d*. They are made in depths from 6 in. to 12 in. of metal

varying in thickness from $\frac{1}{14}$ in. to $\frac{1}{12}$ in. Due to this method of construction the web is always twice as thick as the flanges. Nails may be driven between the flanges for the purpose of fastening nailing strips, etc., to them. Prongs are commonly formed on the lower flanges for use in fastening metal lath. This type of joist is sometimes called *metal lumber*. A floor using strip joist supporting a thin concrete slab is illustrated in Fig. 128.

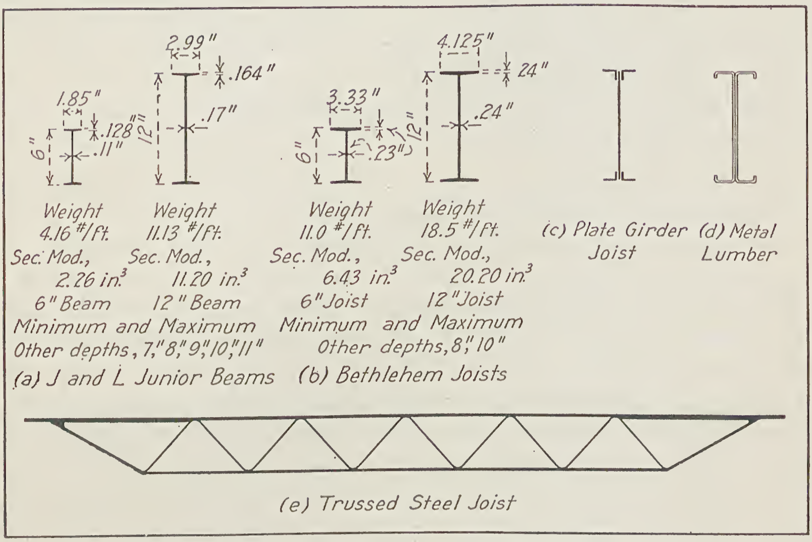



FIG. 91. Light Steel Joists

*Trussed steel joists* are light trusses made in various ways. They are usually of the warren or pratt truss type as shown in Fig. 91*e*. In the bar-joist type the top and bottom chords each consist of two round bars placed side by side and joined by web members formed of a round bar bent back and forth between the chords and electric-arc welded to the chords at the points of contact. In another type the chords are T-sections to which the bar web members are electric-arc welded. A trough-shaped chord section is used in one type. A bar forming the web members fits into the trough at the points of contact. The connection is made by clinching the bar between the sides of the trough. A one-piece truss joist is made by cutting slits in the web of a shallow I-section in such a manner that it can be expanded when heated to form a truss. Truss joists rest on the top flanges of the floor girders and are held in position by clips, bolts, or welds.

The Uniform Building Code of the Pacific Coast Building Officials Conference contains the following clauses concerning steel joist construction:

Steel joists may be rolled structural steel sections, sections built up of rolled structural sections, or shapes made from strip or sheet steel securely spot-welded together so as to form a cohesive structural unit, all of which shall have the general shape or contour of an I-beam; or such steel joists may be of a determinate (capable of stress analysis) truss design built up of rolled steel sections effectively electrically arc-welded together as specified.

Stresses in steel joist shall not exceed the allowable values and no joist under its calculated load shall have a deflection exceeding 1/360 of the span. Bridging shall be installed sufficient to stay the joists laterally and to transmit any horizontal forces in a direction perpendicular to the direction of the joists through the floor panels and into the main structural frame. The actual spacing of the joists center to center shall be determined by their capacity to sustain the loads which they carry and the allowable load-carrying capacity of the floor structure between the members.

When used in buildings of fire-resistive construction, steel joists shall be connected to the supporting beams or girders by electric-arc welding, riveting, bolting or rigidly connecting. Electric-arc welds shall be made on both sides of each bearing, shall be not less than 1 in. in length measured from the starting end to the center of the finishing crater, and shall have a minimum bead of $\frac{1}{4}$ in. When steel joists are supported on masonry, the end bearing shall be not less than 4 in. in length and the ends of such joists shall be provided with approved joist anchors thoroughly bedded in the supporting masonry, placed not to exceed 6 ft. apart. Bearing plates securely welded, bolted, or riveted to the joists shall be provided when required by the design of the joists.

Strip or sheet steel used to produce strip-steel joists shall in no case be less than 0.072 in. in thickness. The flange width of such joists shall not exceed one-half of this depth.

Trussed-steel joists shall be so constructed that the lines of force of all connected members shall intersect at a point or a proper allowance shall be made in the design for any resulting stress. The joints of all trussed-steel joists shall be made by connecting the members directly to one another by electric-arc welds or by rivets of sufficient capacity to develop the ultimate strength of the smallest connecting member. When welds are used, each connection of member to member shall be made with not less than two welds, and each weld shall be not less in length, measured from starting end to the center of the finishing crater, than twice the diameter of the smallest member connected, nor less in cross-sectional area than one-fourth of the cross-sectional area of the smallest member connected. Welds shall be located symmetrically on both sides of all connected members so as to eliminate eccentricity of joints. When sections other than round bars are used, the length and cross-sectional area of the welds shall be the same as those required for round bars of equivalent area.

## ARTICLE 37. STEEL TRUSSES

The various types of steel trusses have been described in Article 26. The members of steel roof trusses are usually composed of one or two angles. Minor members carrying small stresses may be made of a single

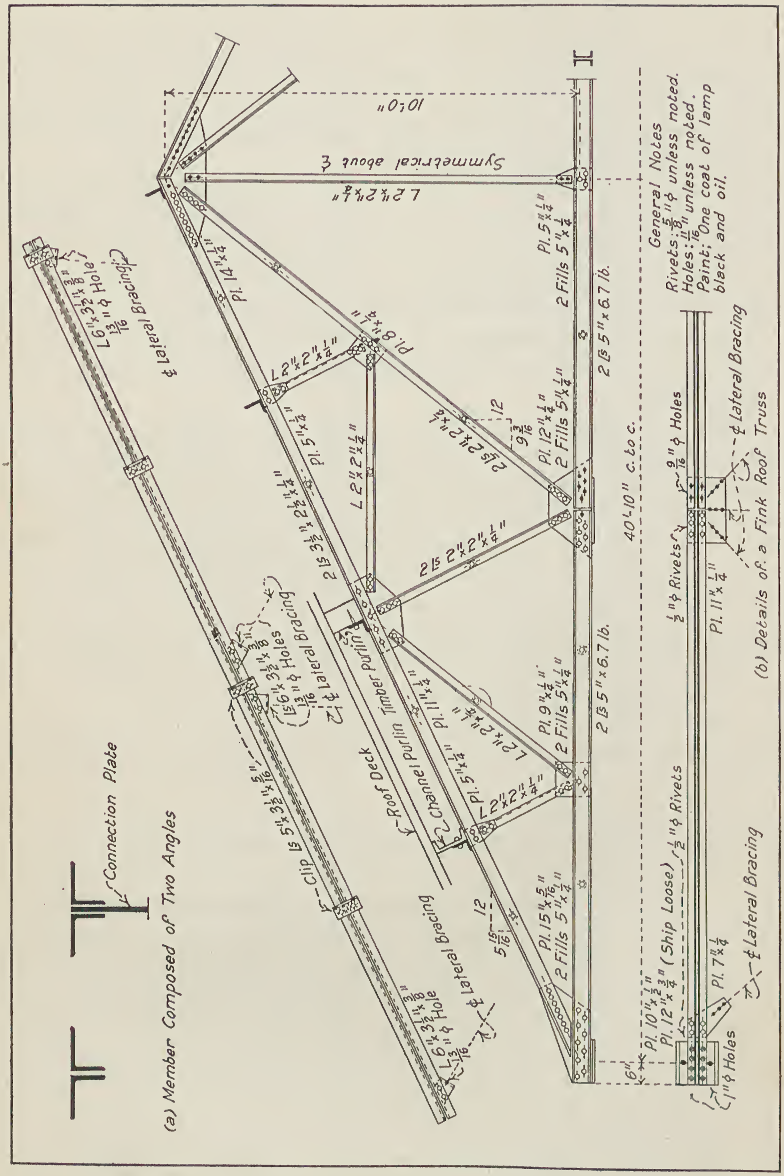



Fig. 92. Steel Roof Truss

angle as small as $2\frac{1}{2} \times 2 \times \frac{1}{4}$ in. in some cases. Members composed of two small angles placed back to back as shown in Fig. 92*a* with sufficient distance between them to permit connection plates to enter are preferred to members composed of one larger angle.

The details of a Fink roof truss are shown in Fig. 92*b*. The members are connected together at the joints by *connection* or *gusset plates* to which the members are riveted, as shown in the figure. These plates vary in thickness from $\frac{1}{4}$ in. to $\frac{5}{8}$ in. and are made large enough to provide for the number of rivets required by the stresses in the members. For trusses having end reactions of 35,000 lb. or over the gusset plates should not be less than $\frac{3}{8}$ in. thick.[1] The rivets are usually $\frac{5}{8}$ in. or $\frac{3}{4}$ in. in diameter.

If the top chord of a roof truss is subjected to bending stresses by loads which are not applied at the joints it may be composed of two angles and

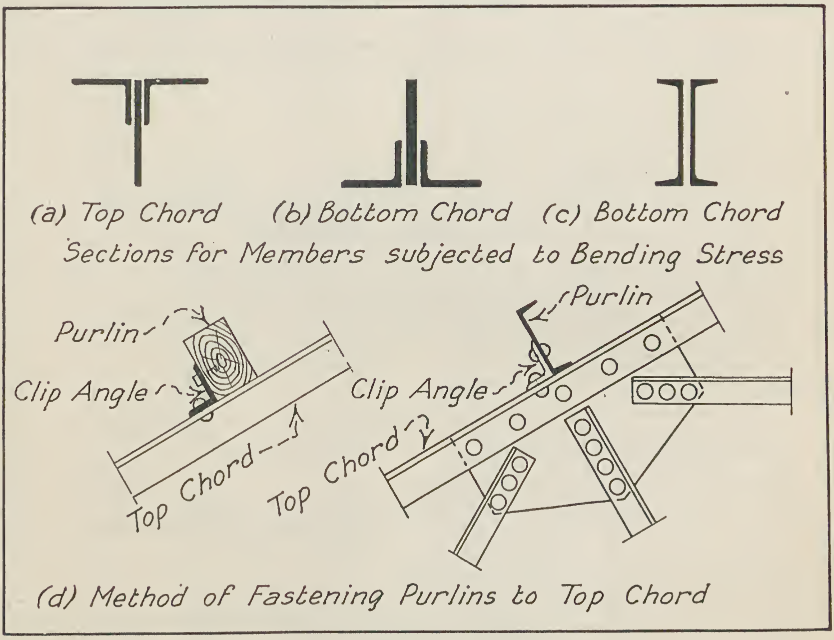



Fig. 93. Steel Roof Truss Details

a plate as shown in Fig. 93*a*. Similarly a bottom chord which is subjected to bending stresses may be made of two angles and a plate as shown in Fig. 93*b*. It is sometimes desirable or necessary to use two channels placed back to back as shown in Fig. 93*c* for the bottom chord.

Timber or steel purlins are fastened to the top chords of steel roof trusses by means of short lengths of steel angles, called *clip angles*, as shown in Figs. 92*b* and 93*d*.

Steel trusses are frequently used as a part of the interior framing of tall buildings to span auditoriums, lobbies, banquet halls, dance halls and other rooms requiring large floor areas free from columns. Such floors

[1] Specifications of American Institute of Steel Construction.

are preferably located at the top or near the top of the building considering economy in the structural framing but other considerations may make it necessary to place these large floor areas in any part of a building. Very commonly they will be on the first floor with fifteen or twenty stories above as shown in Fig. 94*a*. The depth of the truss may occupy one or more stories. It may not be possible to use one of the common types of truss because of doors or hallways for the floor or floors immediately above may have to pass through the truss and will determine its form. Such trusses have to be of very heavy construction. Typical cross-sections of truss members are given in Fig. 94*b*.

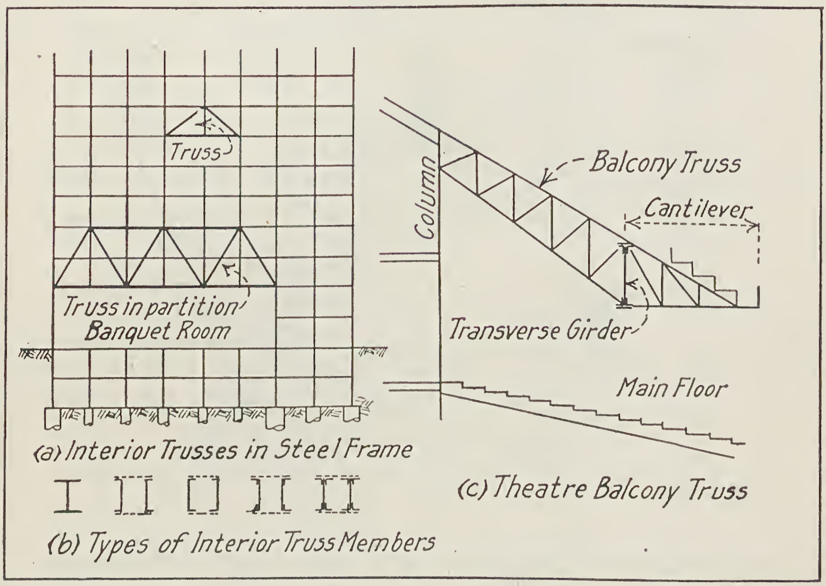



FIG. 94. Interior Trusses

Another common use for steel trusses is to support the balconies of theaters. Columns are of course objectionable on account of their obstruction of the vision so they are eliminated whenever possible. A common form of construction consists of cantilever trusses overhanging a transverse supporting truss or girder as shown in Fig. 94*c*.

## ARTICLE 38. STEEL ARCHES

Structural steel arches are more commonly used than any other type of arch for long spans which are too great for the economical use of trusses. They are used to support the roofs over drill halls, gymnasiums, hangars, etc. The most common form of steel arch in building construc-

tion is that with three hinges as shown in Fig. 95*a* although the two-hinged arch as shown in Fig. 95*b* is used.

The method used in fastening the various members together at the joints is the same as that described for roof trusses. The members are riveted to connection plates.

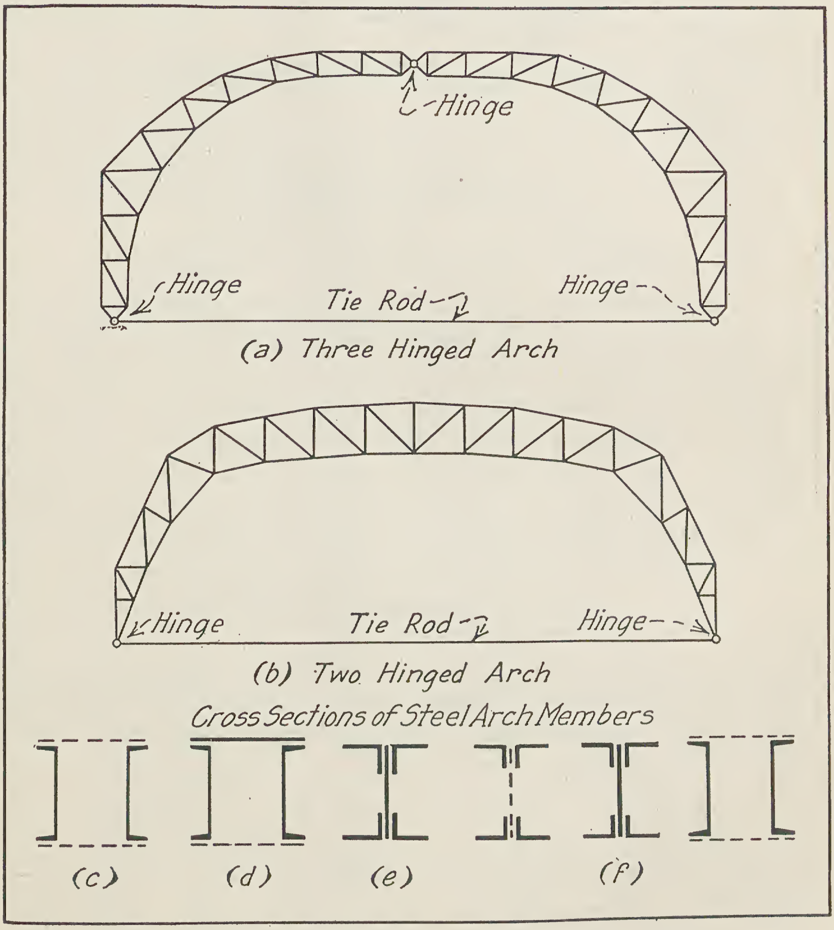



Fig. 95. Steel Arches

The chord members may be made of two channels fastened together with lacing bars as shown in Fig. 95*c* or with a cover plate on top and lacing bars at the bottom as shown in Fig. 95*d* or of four angles and a web plate as shown in Fig. 95*e*. The web members may consist of four angles laced or with a web plate, or of two channels laced as shown in Fig. 95*f*. Two angles placed back to back as described for roof trusses

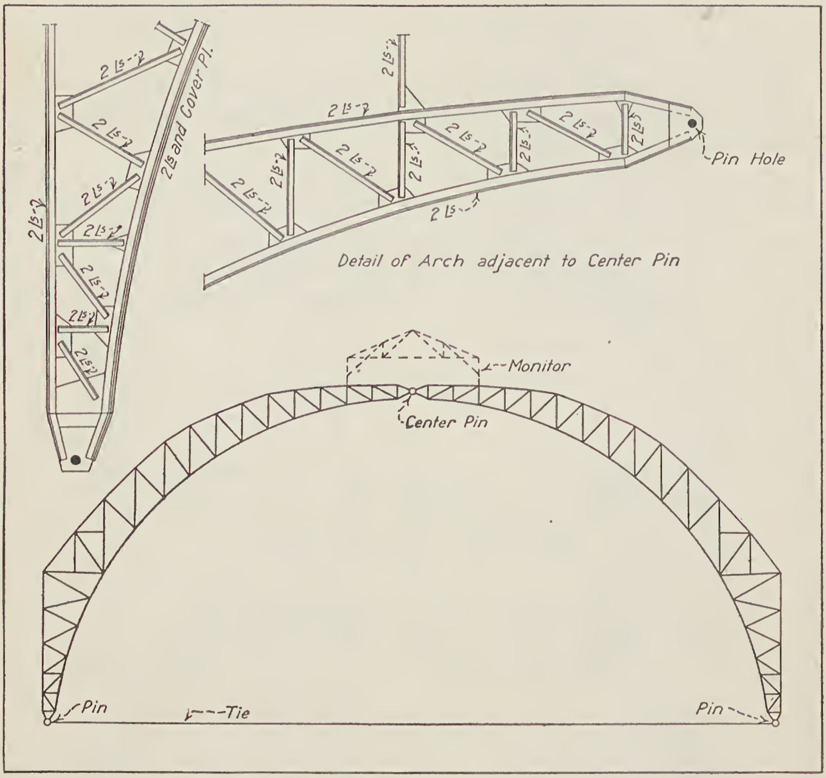



Fig. 96. Three-hinged Steel Arch

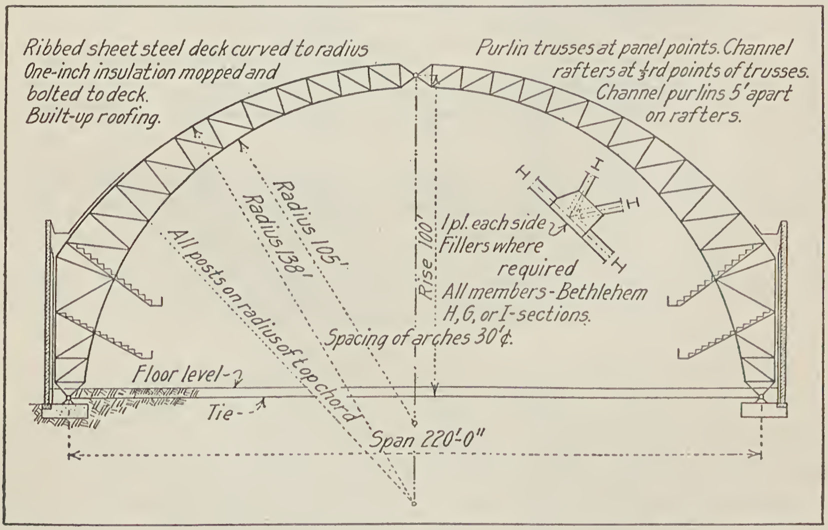



Fig. 97. Three-hinged Arch, University of Minnesota Field House

are extensively used in arch construction for chord and web members. Members composed of I-beams or H-sections are also used. See Fig. 97.

The foundations may be designed to take the horizontal thrusts of the arch, but ties passing under the floor and joining the two end joints as shown in Figs. 95 to 97 are more commonly used. These ties may be rods, steel sections, or the floor itself may be used when properly designed to carry the thrust.

In the three-hinged arch illustrated in Fig. 96[1] most of the members are composed of two angles placed back to back with a sufficient distance between them to permit the connection plates to enter. Near the ends the lower chord is reinforced with cover plates.

Balconies are often provided as shown in Fig. 97.

## ARTICLE 39. STRUCTURAL STEEL FRAMING

**General Methods.** — Structural steel members are fastened together by means of plates and angles held in place by rivets or bolts or by welding. In general, connections should be riveted but bolts may be used in the construction of unimportant members where there is no vibration, in roof purlin connections, and in some cases the connections between beams and girders may be bolted with good results. The connections between girders and columns should always be riveted and the various parts of beams, girders, columns, and trusses should always be riveted together. Where bolts are used the nuts should be prevented, in some way, from working loose.

Welding has been used to a limited extent in place of riveting but this method of fastening members together is still in the experimental stage.

**Riveting.** — Rivets are used in fastening the various parts of a structural steel member together and in connecting members together. The

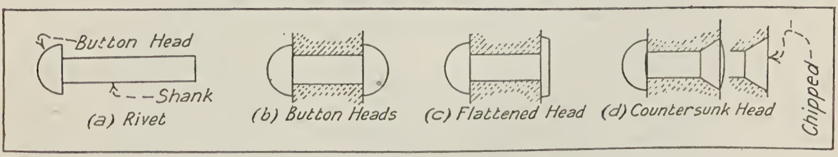



Fig. 98. Types of Rivet Heads

first operation is usually performed in the shop and is called *fabricating* and the last operation is usually performed at the site as the building is being *erected*. The rivets used in building construction are made of soft steel. They usually consist of a hemispherical button-shaped head and a cylindrical shank as shown in Fig. 98*a*. In driving, a rivet is heated

[1] Adapted from Engineering News-Record, Vol. 75, p. 152.

red hot and placed in a hole through the members which it is to assist in connecting. The projecting end is then upset to form a head, using a pneumatic or hydraulic riveter, there being a depression in the head of the riveter to give the rivet head the proper shape. The other end of the rivet is held in place by a *dolly* or similar contrivance, while the rivet is being driven.

Rivets are driven in the field or on the job by portable pneumatic riveters called *guns*. Rivet heads may be of various shapes to suit special conditions. The *button head* shown in Fig. 98*b* is the shape

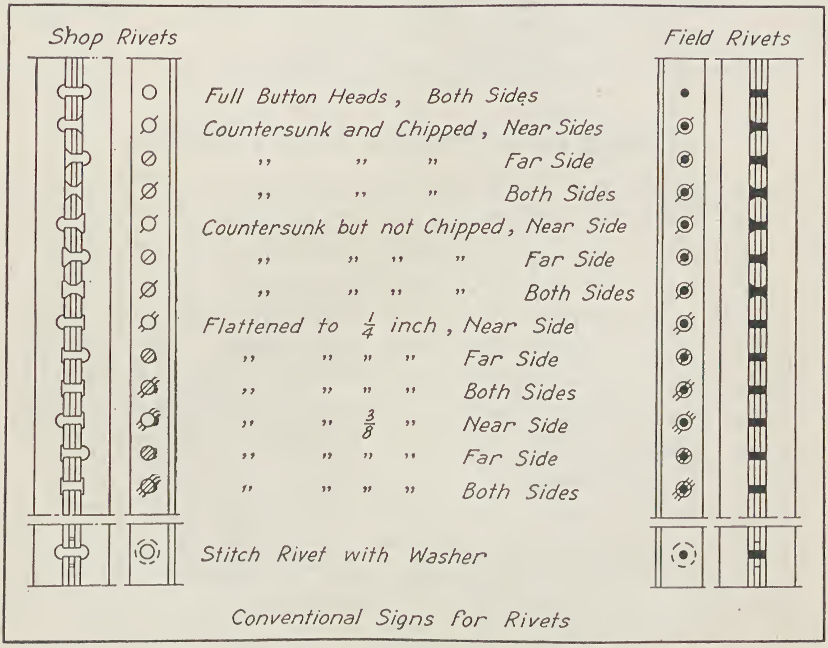
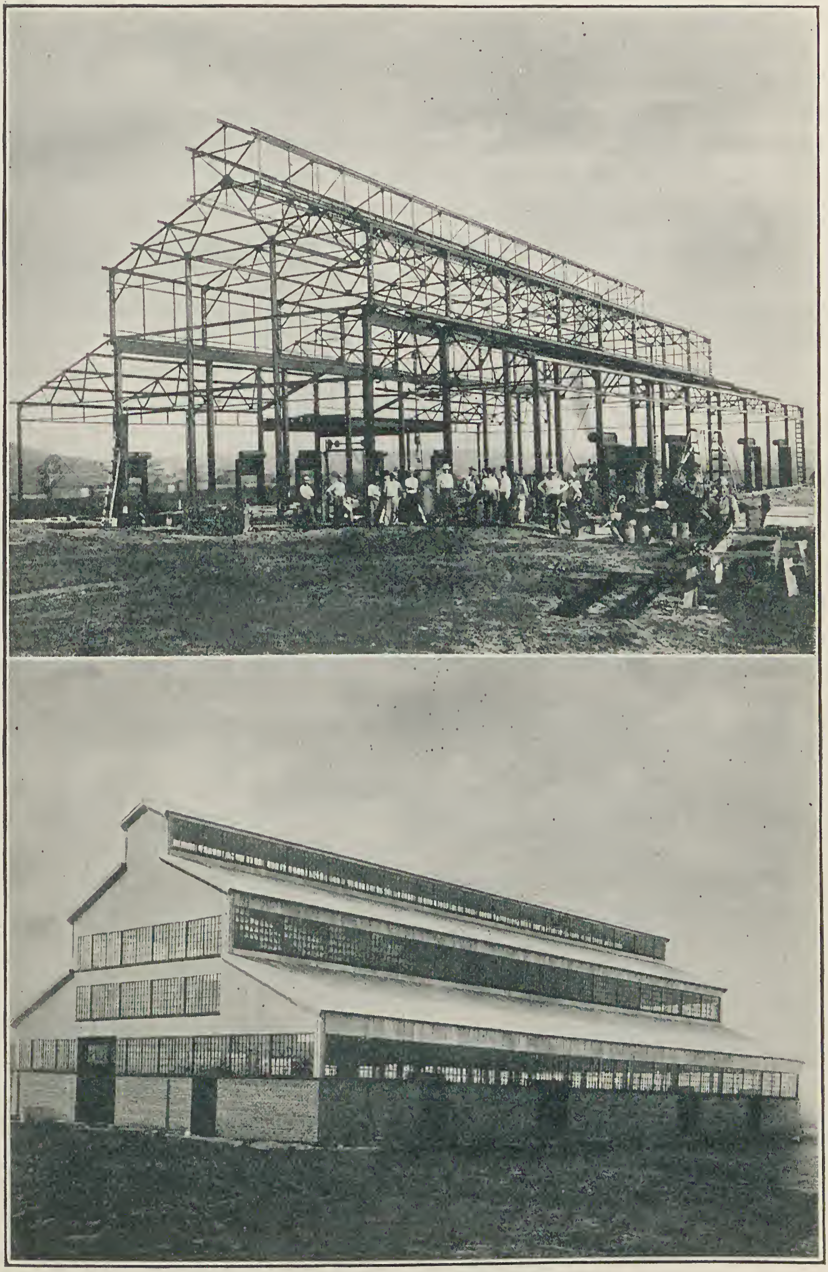



Fig. 99. Conventions for Rivets

usually used. To provide clearance, the *flattened head* shown in Fig. 98*c* may be used or the *countersunk head* shown in Fig. 98*d*. Countersunk heads which have been chipped flush with the surface must be used on bearing plates and column bases so that they will not interfere with the bearing.

In structural steel details the heads of shop-driven rivets are shown in plan by circles of the size of the head but field rivets are indicated, in plan, by circles the size of the holes. In the case of field rivets the circles are filled in black.

The conventions used on structural drawings to represent rivets of various types are shown in Fig. 99.



*Courtesy of Kansas City Structural Steel Co.*

FOUNDRY BUILDING
Steel Frame and Completed Building.

For very light work, rivets $\frac{1}{2}$ in. and $\frac{5}{8}$ in. in diameter are used. For ordinary work the most common size is probably $\frac{3}{4}$-in. but $\frac{7}{8}$-in. rivets are extensively used. For heavy work 1-in. and $1\frac{1}{8}$-in. rivets are used. There are certain recognized practices concerning the maximum and minimum spacings, the maximum and the minimum distance which rivets should be placed from the edge of a member, and many other factors some of which are as follows:[1]

The minimum distance between the centers of rivet holes (pitch) shall be three diameters of the rivet; but the distance shall preferably be not less than $4\frac{1}{4}$ in. for $1\frac{3}{4}$-in. rivets, 4 in. for $1\frac{1}{8}$-in. rivets, $3\frac{1}{2}$ in. for 1-in. rivets, 3 in. for $\frac{7}{8}$-in. rivets, $2\frac{1}{2}$ in. for $\frac{3}{4}$-in. rivets, 2 in. for $\frac{5}{8}$-in. rivets and $1\frac{3}{4}$ in. for $\frac{1}{2}$-in. rivets.

The maximum *pitch* (spacing center to center) in the line of stress of compression members composed of shapes shall not exceed 16 times the thickness of the thinnest outside plate or shape nor 20 times the thickness of the thinnest enclosed plate or shape with a maximum of 12 in. and at right angles to the direction of stress the distance between lines of rivets shall not exceed 30 times the thickness of the thinnest plate or shape. For angles in built sections with two gage lines, with rivets staggered, the maximum pitch in the line of stress in each gage line shall not exceed 24 times the thickness of the thinnest plate with a maximum of 18 in. (Some designers consider these spacings too large.)

The pitch of rivets at the ends of built compression members shall not exceed four diameters of the rivets for a length equal to one and one-half times the maximum width of member.

The minimum distance from the center of any rivet hole to a sheared edge shall be $2\frac{1}{4}$ in. for $1\frac{1}{4}$-in. rivets, 2 in. for $1\frac{1}{8}$-in. rivets, $1\frac{3}{4}$ in. for 1-in. rivets, $1\frac{1}{2}$ in. for $\frac{7}{8}$-in. rivets, $1\frac{1}{4}$ in. for $\frac{3}{4}$-in. rivets, $1\frac{1}{8}$ in. for $\frac{5}{8}$-in. rivets, and 1 in. for $\frac{1}{2}$-in. rivets. The maximum distance from any edge shall be 12 times the thickness of the plate, but shall not exceed 6 in.

Material may be punched to form holes $\frac{1}{16}$ in. larger than the nominal diameter of the rivets where the thickness of the metal is equal to or less than the diameter of the rivets, plus $\frac{1}{8}$ in. When the metal is thicker than the diameter of the rivet, plus $\frac{1}{8}$ in., the holes shall be drilled or be *sub-punched* and *reamed.*

Rivets are to be driven hot and whenever practicable, by power. Rivet heads shall be made hemispherical in shape and uniform in size throughout the work for the same size rivet, full, neatly finished, and concentric with the holes. Rivets, after driving, shall be tight, completely filling the holes, and with heads in full contact with the surface. Rivets driven in the field shall be heated and driven with the same care as those driven in the shop. Usually the heads of the rivets are approximately hemispherical in shape but when such rivets would interfere with other parts they may be flattened or countersunk.

The method of riveting together the various parts of the column section shown in Fig. 87*d* is illustrated in Fig. 87*p*. The use of lacing

[1] Standard Specifications for Structural Steel for Buildings, American Institute of Steel Construction.

bars to fasten the parts of a column together is illustrated in Fig. 87*q*. These figures show only a part of the length of a column.

**Welding.**[1] — There are five welding processes in use but they are not all applicable to structural work. These methods are: Forge or fire welding, thermit welding, resistance welding, and oxy-acetylene or gas welding.

In *forge welding* the pieces to be welded are heated to welding temperature in a forge and after placing them in contact they are hammered together on an anvil.

In *thermit welding* heat is produced by the chemical combustion of iron oxide and powdered aluminum which when ignited release molten metal and raise the parts with which they come in contact to a very high temperature forming a weld when the pieces are properly arranged.

In *resistance welding* the pieces to be welded are placed in contact and heat is generated by an electric current passed across the junction. Because of the high resistance at the junction due to the imperfect contact the metal at the junction is heated and becomes plastic so when pressure is applied a weld is formed. This process is used in *spot welding* light structural shapes such as used in metal lumber.

In *oxy-acetylene welding*, the flame produced by the burning of oxygen and acetylene gas is used in heating the surfaces to be welded. Extra metal is supplied at the junction by melting a filler rod. This method is extensively used in repair work and to a certain extent in structural fabrication and erection.

In *electric-arc welding*, the pieces to be welded are heated by an electric arc. The arc forms between the work to be welded and an electrode held in the operator's hand with a suitable holder. The hand electrode may be a metallic wire as in metallic-arc welding or a carbon rod as in carbon-arc welding. The arc heats the small area to the melting point almost instantly and if a metallic rod is used its tip gradually melts off and supplies additional metal for the weld. The metallic process can be carried on in any position but the carbon process cannot be used for vertical or overhead welding. This method is used more than any other in structural fabrication and erection.

There are four types of weld as shown in Fig. 100*a*: the *butt weld*, the *lap weld*, the *fillet weld* and the *rivet weld*. The types are all evident from the figure except the rivet weld. In making a rivet weld the pieces to be welded are lapped after holes have been drilled in the top piece. The welding metal is deposited in the holes in the top piece and forms solid plugs welded to the surface of the lower piece and to the sides of the holes of the upper piece.

[1] Abstracted from Arc Welding published by the Lincoln Electric Co.

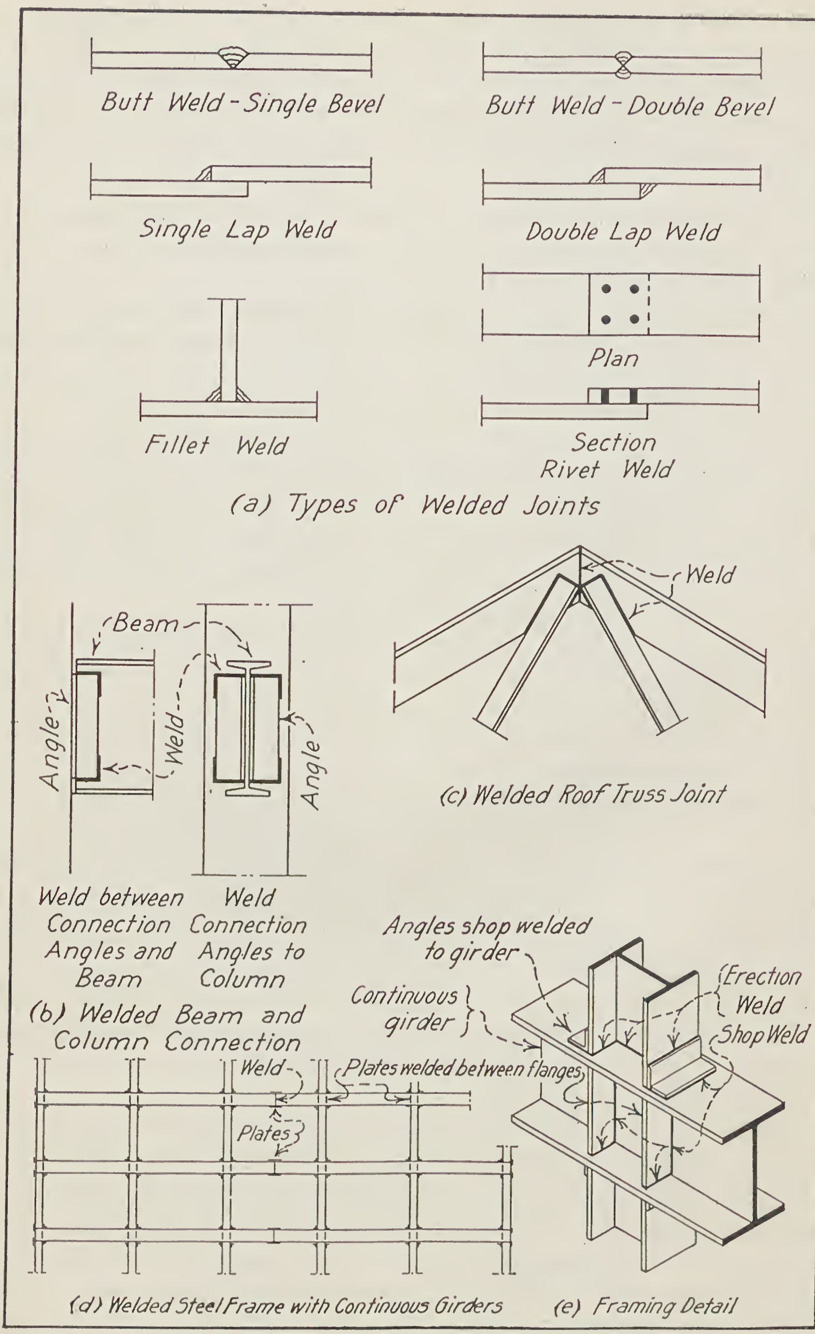



Fig. 100. Welding Details

Some welded structural joints are shown in Fig. 100*b* and *c*. It is usually necessary to make provision for the temporary bolting of field joints to hold members in position while welds are being made.

In the common form of steel building frame the columns are continuous while the girders are fitted in between them and connected to them in various ways. The frame illustrated in Fig. 100*d*[1] consists of continuous girders with the columns fitted in between them. For a low building in which the direct loads and bending moments in the columns are relatively small, this type of construction has certain advantages for it is much easier to splice a member which carries stresses which are mainly compressive than it is to splice a member carrying large bending stresses. In order to assist in transmitting the column stresses through the webs of the girders, plates are welded between the flanges of the girders as shown in Fig. 100*e*. Column sizes can be changed for each story if desired.

The Uniform Building Code of the Pacific Coast Building Officials Conference contains the following clauses concerning welding:

Electric-arc welding may be used (in place of riveting or bolting) for connecting structural steel or wrought iron parts or members to one another, but in no case shall the stresses in such joints exceed the allowable unit stresses given in this code.

The electrode wire shall conform to the American Welding Society Specification E No. 1-A or E No. 1-B.

All portions of the members at the point of welding shall be freed from rust, paint and other foreign matter by brushing the surfaces with an iron brush, by chipping or by hammering.

The Building Inspector shall require the welding operator to furnish evidence of his experience and competence in structural arc welding and may require the welder to make sample butt welds. Such sample welds must show an average strength of 45,000 lb. per sq. in. with no sample developing a tensile strength of less than 40,000 lb. per sq. in.

When electric spot or resistance welding is used the portion of the members to be welded shall be thoroughly cleaned of rust, scale or other foreign matter by pickling in a suitable acid before welding.

**Lap and Butt Joints.** — Joints provided by riveting plates or parts of members which lap over each other, as shown in Fig. 101*a* are called *lap joints*. Those formed by butting the ends of two parts together and fastening them together by rivets passing through a splice plate or connection plate, as shown in Fig. 101*b* are called *butt joints*.

**Column Splices.** — Steel column sections are usually made constant for two story heights. Due to the change in the load on a column at

[1] American Contractor, November 24, 1928, p. 20.

each floor it would be possible to save column material by reducing the column section in each story. This practice would be undesirable because the cost of the splices, and the increase in erection costs would probably offset any saving in column section. In order that the splices

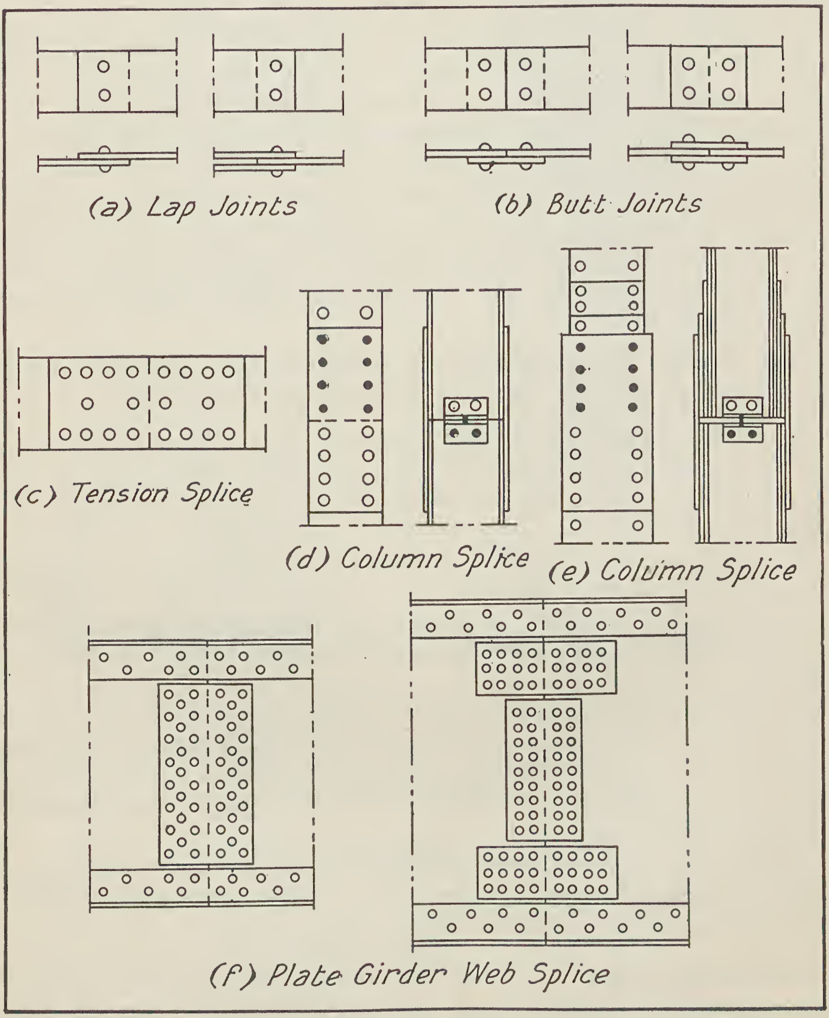



Fig. 101. Splices in Steel Members

will not interfere with the beam and girder connections they are commonly made about 2 ft. above the floor line.

The abutting ends of the columns at the splice are accurately milled so that the compressive stresses can be transferred directly from the upper column to the lower column by bearing. Splice plates are riveted to the

flat sides of the columns and extend a short distance above and below the abutting ends. The functions of these plates are to hold the two sections in line, to resist bending stresses due to wind and other causes, and to provide lateral rigidity. They are not relied upon to transfer any of the direct load from one section to the other with the possible exception of columns carrying very light loads.

If the two sections are of the same width as in constant-depth columns the splice is very simple as shown in Fig. 101*d*. If the widths are not the same, the difference in width is taken up by the fill plates as shown in Fig. 101*e*. If the difference in width is so great that the flanges of the upper columns do not bear on those of the lower column a horizontal bearing plate is inserted between the abutting ends as shown in the figure.

**Splices in Plate Girder Webs.** — The size of plates available for webs of plate girders is limited so it is often necessary to splice these web plates. Two forms of web splices are shown in Fig. 101*f*.

**End Connections of Bars and Rods.** — Bars and rods are used chiefly for lateral bracing and for ties and hangers. Their use is decreasing, as rigid members such as angles are being substituted wherever possible.

The ends of rectangular bars are provided with eyes as shown in Fig. 102*a* and the bars are called *eye-bars*. This type of member is only used with pin joints as described later and is therefore not used to any extent in building construction where the joints are usually riveted or bolted.

The ends of round and square bars may be provided with loops as shown in Fig. 102*b*. Such bars are called *loop bars* and are only used with pin joints as described later and therefore have little use in building construction.

The ends of round or square bars may be threaded to receive nuts to form an end connection. Several connections making use of nuts on threaded ends are shown in Fig. 102*c*. When long bars are used it is usually economical to enlarge the end of the bar so that the area of the section at the root of the threads is somewhat greater than the area in the body of the bar. A smaller bar can then be used, for the threads do not reduce the sectional area. These enlarged ends are called *upset ends* and are illustrated in Fig. 102*e*.

The *clevis* shown in Fig. 102*g* is a very convenient form of end connection for round and square bars. Upset ends are usually provided as explained in the previous paragraph. The pin in the clevis may be a *cotter pin* as shown in Fig. 102*g* or an ordinary bolt and nut. The small split pin inserted in the larger pin is called a *cotter*.

**Adjustable Bars.** — It is often desirable to make tension rods and bars adjustable so that they may be tightened. Two devices are used for this

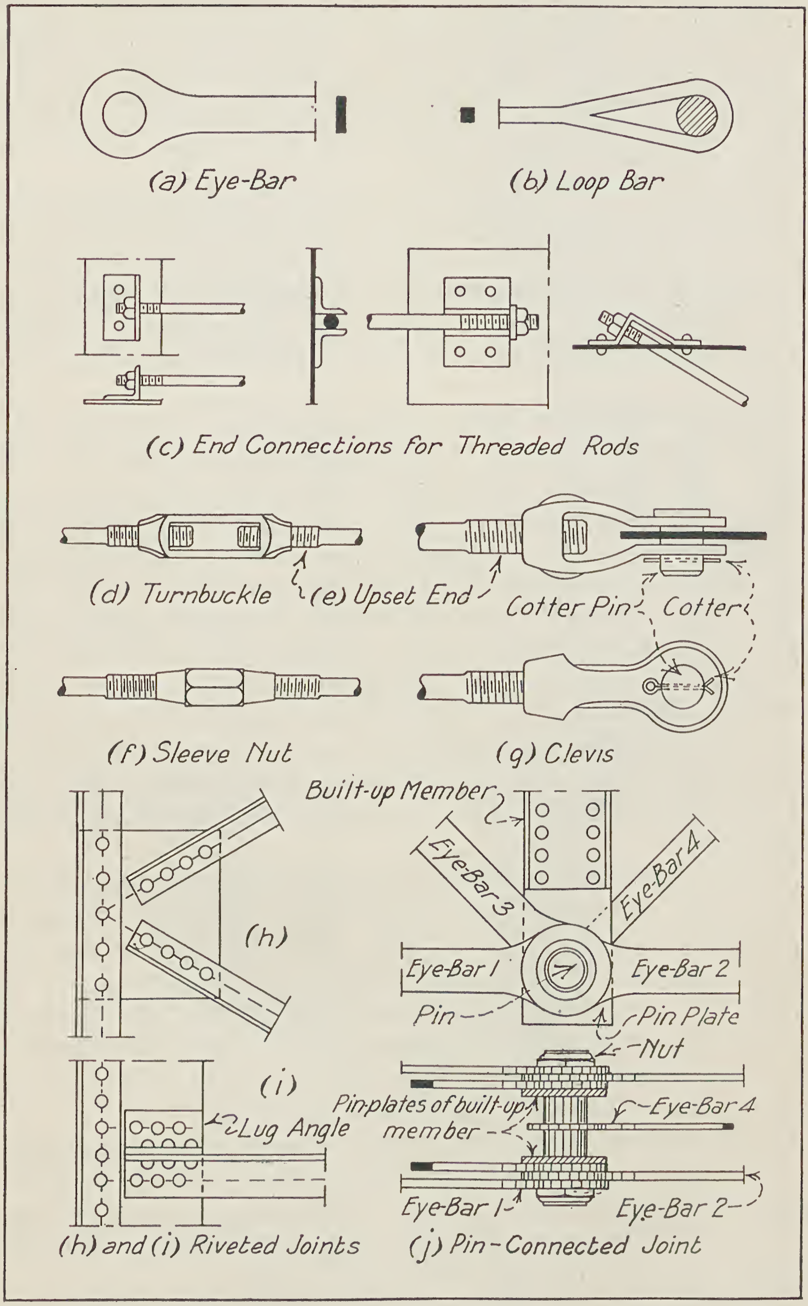



FIG. 102. End Connections for Steel Tension Members

purpose, the *turnbuckle* shown in Fig. 102*d* and the *sleeve-nut* shown in Fig. 102*f*. In both of these devices a right-hand thread is used at one end and a left-hand thread at the other so that the ends of the bar may be drawn together or pushed apart by turning the turnbuckle or sleeve-nut in the proper direction.

**Connection or Gusset Plates and Riveted Joints.** — Tension and compression members composed of angles, channels, and various forms of built-up members usually have their ends riveted to plates called *connection* or *gusset plates*. The number of rivets required is determined by the stress in the member. The end connection of a member composed of a single angle is shown in Fig. 102*h*. The use of a *lug angle* as shown in Fig. 102*i* is sometimes desirable. The detail drawing of a roof truss shown in Fig. 92*b* will illustrate the use of connection or gusset plates.

**Pin Connected Joints.** — The joints at the points of intersection of the members of a truss are usually formed by riveting the various members to connection or gusset plates as just described. Another form of joint which has a limited use in building construction but which is quite widely used in bridge construction is the pin joint, as illustrated in Fig. 102*j*. The various built-up members may be riveted to separate plates which are connected by a pin. These plates are called *pin plates*.

**Beams and Girder Connections.** — The usual method for connecting beams to girders is with *framed connections* as illustrated in Fig. 103*a*. The size of angles and the number of rivets to be used for each size of beam has been standardized to quite an extent and such connections are called *standard connections*. One angle is sometimes used instead of two. Very often it is necessary to keep the top flanges of the beam and the girder at the same elevation. In this case the beam flange must be cut to clear the flange of the girder as shown in Fig. 103*b* and the beam is said to be *coped*. In many cases the beam may rest on top of the girder and the only connection required is bolts through the flanges, as shown in Fig. 103*c* to hold them together. Channel purlins are usually supported on the sloping top chords of roof trusses by means of the *clip angle* connection shown in Fig. 103*d*. This connection may be bolted instead of riveted if desired.

**Connection of Beams and Girders to Columns.** — There are two types of connections used between beams or girders and columns, the *framed connection* type and the *seated* type.

The framed connection type illustrated in Fig. 103*e* consists of two angles which are riveted to the beam or girder in the shop, the rivets between the angles and the column being driven in the field. A shelf angle may be provided to support the beam or girder during erection. This is called an *erection seat*.

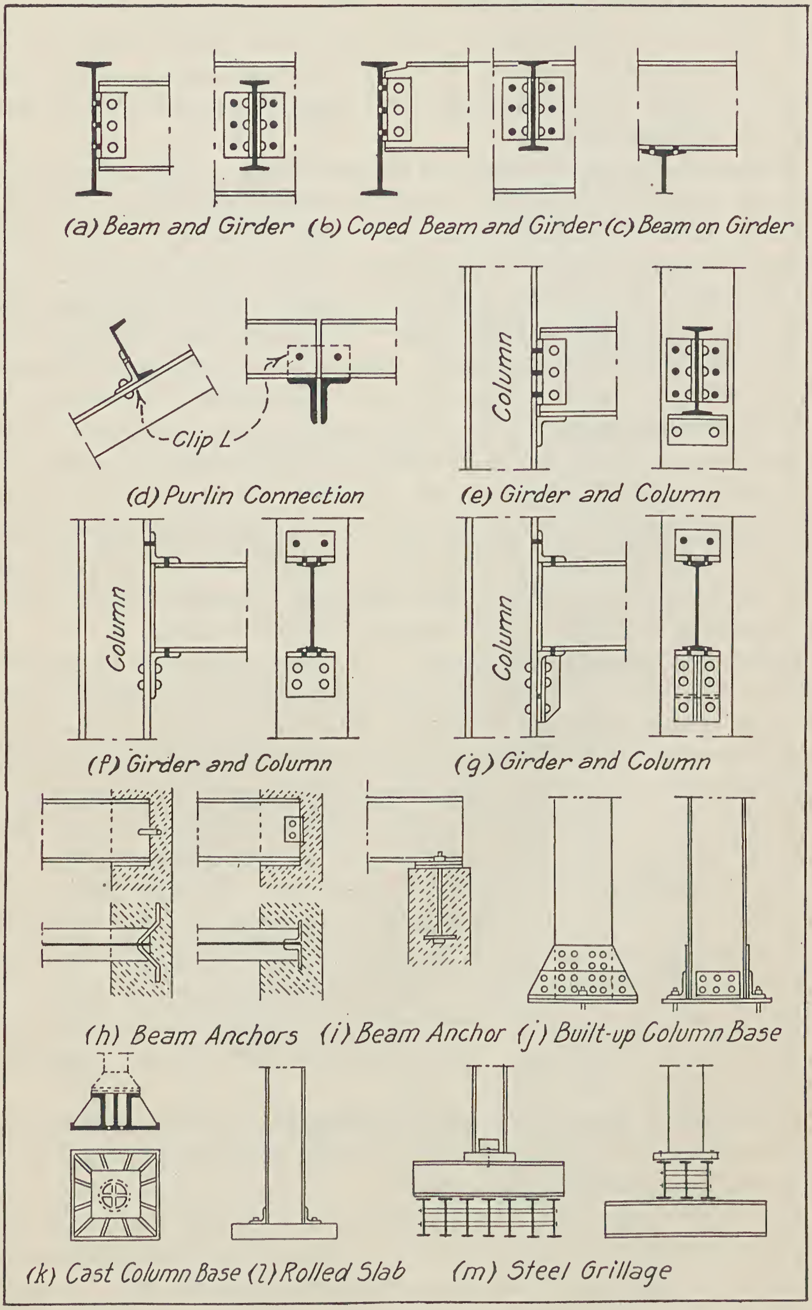



FIG. 103. End Connections and Column Bases

The seated type of connection shown in Fig. 103*f* consists of an angle at the bottom side of the beam which is shop-riveted to the column and an angle at the top which is field-riveted to the beam and column. For large reactions it is necessary to provide one or two *stiffener angles* to support the outstanding leg of the bottom angle as shown in Fig. 103*g*.

The shop work is more simple on the seated type and fewer field rivets are required but this type may project through the fireproofing if used in connecting to column flanges, in which case the framed connection is used.

**Wall Supports for Beams and Girders.** — Steel beams and girders may be built into masonry walls. *Bearing plates* are provided to distribute the reaction over a larger area and anchors as shown in Fig. 103*h* tie the beam and wall together. Where beams and girders are not built into the wall, *anchor bolts* as shown in Fig. 103*i* are provided.

**Column Bases.** — The load at the lower end of a column must be transferred to a concrete footing or pier which in turn transfers the load to the ground. If the end of the steel column were permitted to rest directly on the concrete, the latter would be crushed where the two came in contact because the working stress in the steel is much greater than the strength of the concrete in bearing. It is therefore necessary to distribute the column load over a large area of the footing. This is done by means of the *column base*. Bases for steel columns may be divided into four classes:

1. Built-up bases made from structural sections as shown in Fig. 103*j*.
2. Cast bases of steel or cast iron as shown in Fig. 103*k*.
3. Rolled-steel slabs as shown in Fig. 103*l*.
4. Steel grillages as shown in Fig. 103*m*.

Built-up bases are suitable for light loads but where it is necessary to distribute the column load over a considerable area the cast-iron or cast-steel bases may be used, cast steel being much stronger and more reliable than cast iron. Recently the rolled-steel slabs have come into use. They are more economical and reliable than the cast-iron bases and more economical than the cast-steel bases. The end of the column is milled and bears directly on the steel slab. A simple connection is made between the column end and the slab by means of two angles. Slabs are available up to 12 in. in thickness but slabs over 6 in. thick are not usually economical.

The following statements concerning column bases are taken from the Engineering Standards of the American Bridge Company:

Rolled-steel slabs, instead of beam grillages should be used where the required length of beams is 3 ft. or less. In general, preference is to be given to the use of slabs bearing directly on the concrete.

Single-tier grillages should be used in preference to double-tier grillage.

Column bases with wing-plates and stiffeners should not be used.

Slabs 4 in. thick or less may be straightened true and smooth in the hydraulic press. Slabs over 4 in. thick should be planed where the surface has a steel bearing. Surfaces bearing on concrete need not be planed, but in order that slabs may be set true and level, proper allowance should be made for grouting between slabs and concrete.

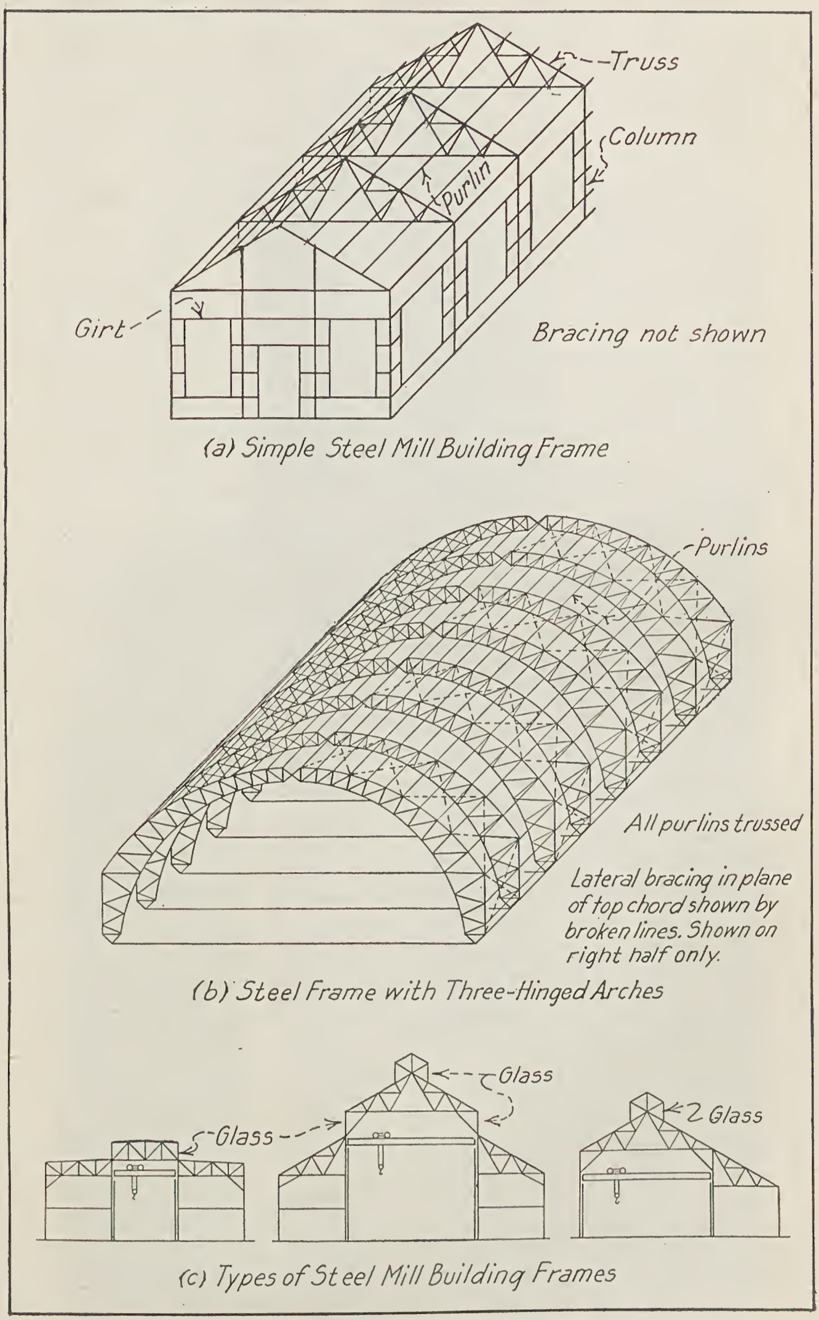
**Wind Bracing for Mill Buildings.** — Buildings must be designed to resist the horizontal forces due to wind as well as the vertical forces due to the weight of the buildings and their contents. Provision must also be made for the lateral thrust of cranes and other equipment.

A simple steel mill building frame with lateral bracing omitted is shown diagrammatically in Fig. 104*a*. The steel frame for a building with three-hinged arches is shown in Fig. 104*b*. The arches are braced in pairs as shown. Several types of steel mill building frames are shown in Fig. 104*c*. These are provided with latest bracing as described in the following paragraphs. Three types of wind bracing are used in steel mill buildings. The simplest type makes use of knee-braces to brace the columns rigidly to the trusses as shown in Fig. 105*a*, or trusses with considerable depth at the ends are rigidly fastened to the columns as shown in Fig. 105*b*. This type of construction provides bracing to resist wind forces on the side of the buildings but wind forces against the ends of the buildings are resisted by cross bracing in the plane of the sides or by a rigid lattice girder just below the eaves as will be explained in the next two methods.

Another method of bracing steel mill buildings to resist wind forces consists of providing cross bracing in the plane of the bottom chord of the truss to make the building rigid from end to end, in this plane. In addition to this bracing the sides and ends are made rigid by diagonal bracing so that the whole structure acts like a rigid box. This method of bracing is shown in Fig. 105*c*. It is not necessary to provide diagonal bracing in all of the bays (spaces between columns) on the sides. Bracing is also provided in the plane of the top chord to hold the tops of the trusses in position but this bracing is not essential to the wind bracing system so it is not shown in the figure. It is evident that this system might interfere seriously with the windows and doors.

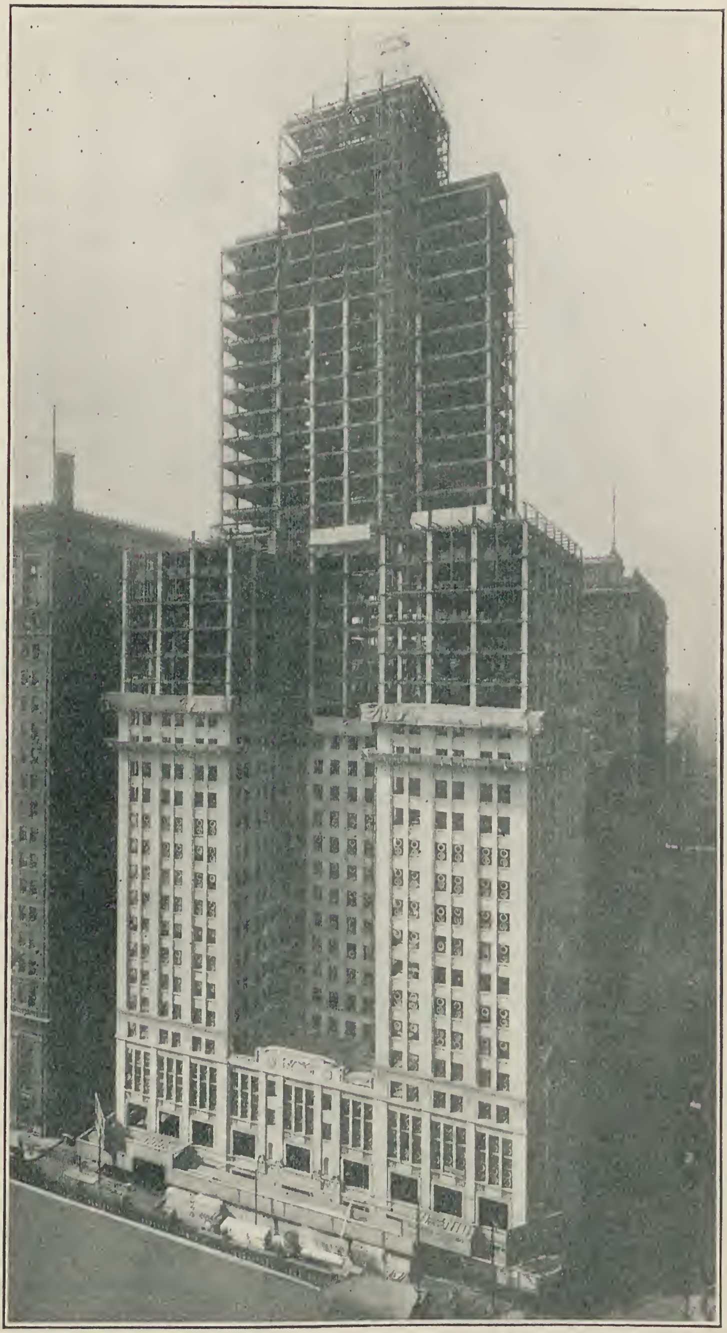
A third system provides lattice girders in the sides and ends to make them rigid. The bracing in the plane of the bottom chord is the same as in the previous method. See Fig. 105*d*.

**Wind Bracing for Tall Steel Buildings.** — In tall buildings of skeleton construction such as office buildings the providing of adequate bracing to resist wind is an important feature of the design. If a frame as illus-



(a) Simple Steel Mill Building Frame
(b) Steel Frame with Three-Hinged Arches
(c) Types of Steel Mill Building Frames

FIG. 104. Framing for Steel Buildings



*Dilks Construction Co., Builders* *D. H. Burnham & Co., Architects*

THE BANKERS BUILDING, CHICAGO, ILL.

trated in Fig. 106*a* is subjected to lateral forces such as those due to wind it would collapse by distorting as shown in Fig. 106*b*. In low buildings of considerable width the stiffening effect of the panel walls and partition and the rigidity of the joints between the girders and columns may be sufficient to provide satisfactory resistance to wind forces but this is not

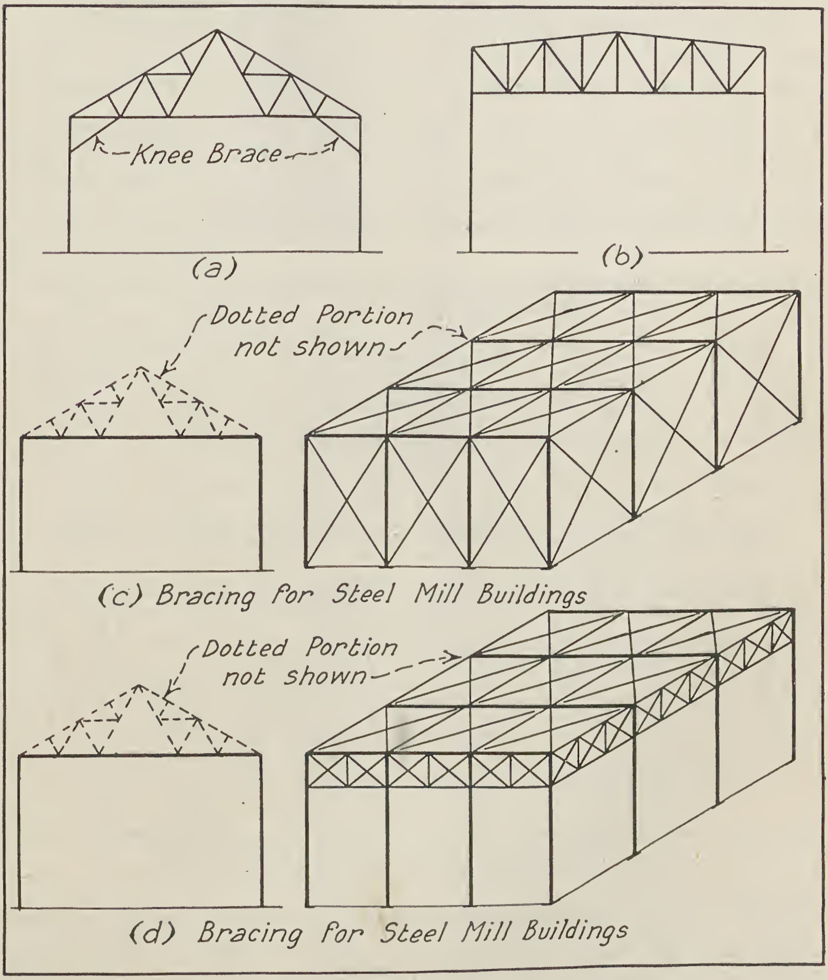



FIG. 105. Wind Bracing for Steel Mill Buildings

the case with tall buildings. Some codes state that buildings less than 150 ft. in height whose least width is greater than one-fourth of the height need have no special provision for wind.[1] Others place the limit of

[1] Building Code of the City of New York.

height at 100 ft. and require that the least width be one-third of the height in order that the effect of wind may be disregarded.[1] The magnitude of the wind load is considered in Article 3.

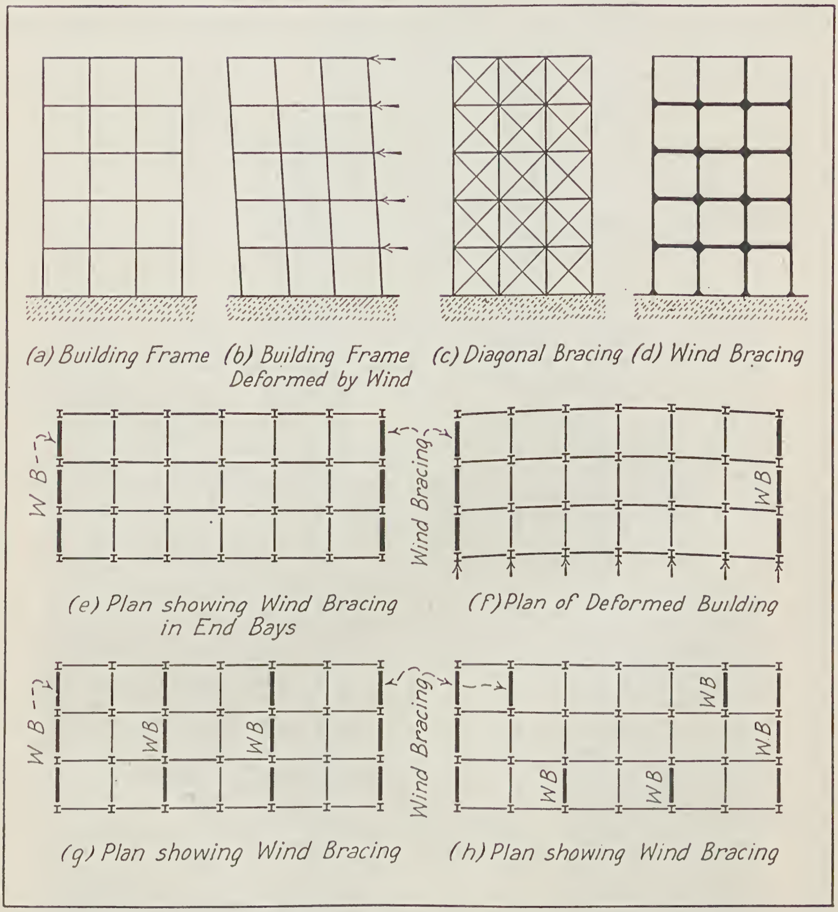



Fig. 106. Wind Bracing for Steel Office Buildings

In the design of tall buildings the structural frame is usually considered as carrying the entire wind load but some building codes[2] and some engineers[3] consider that the walls and partitions will carry a part of this load, leaving only the remainder to be carried by the structural frame.

Several types of wind bracings have been devised. The most direct

[1] Building Laws of San Francisco.

[2] Building Code of the City of Detroit, Mich.

[3] Editorial in the Canadian Engineer, November 16, 1926; Engineering and Contracting, July 1928, p. 363.

type consists of diagonals crossing the vertical panel between the columns and the floor girders as shown in Fig. 106*c*, but it is evident that this method is limited in its application because of its interference with the use of the building and with the locating of windows and doors even though it is necessary to brace only a relatively small number of panels, as will be explained later.

If sufficiently rigid connections are provided between the girders and columns as shown in Fig. 106*d*, a skeleton frame will be able to resist lateral forces. It is evident that there is a tendency to bend the columns and girders when this type of bracing is used, so it is necessary to consider the bending stresses in the design of these members. This type of wind bracing can be so arranged as to interfere very little with the design and use of a building and is the only type which is used to any extent at the present time.

The group of braced vertical panels in a single vertical plane designed to resist wind stresses is called a *wind bent*. It is not necessary to make all of the panels of a building rigid although this may be desirable as it reduces the size of the bracing. As a rule, wind bents can be placed in the outside walls, as shown in Fig. 106*e* more conveniently than elsewhere. With this arrangement, the floors of a building tend to deform as shown in Fig. 106*f* under the action of wind forces. The floors used in modern building construction are usually rigid enough to carry the wind load to the wall bents but if they are not, special bracing can be provided in the plane of the floors. It may be undesirable or impossible to place all of the required wind bracing in the outside bents of a building in which case some of the interior bents may be utilized. It is desirable but not necessary for these to be continuous across the building as shown in Fig. 106*g* but wind bents may be distributed throughout the building as shown in Fig. 106*h*, each being designed to carry its part of the wind load. They should be so placed that there is no twisting effect in the frame due to greater rigidity on one side than on the other.

In buildings which diminish in size in the upper stories, wind bents located in the exterior walls may be continued down through the interior of the lower part of the building or, in some cases, it may be desirable to transfer the wind loads to wall bents in the lower stories as shown in Fig. 107*a*. The horizontal effect of the wind or the upper section may be transferred to the wall bents or other bents in the lower stories by means of a heavy concrete floor slab where the building changes section, or by special bracing in the floor. The vertical reactions of the columns of the wind bents are transferred directly down through the corresponding columns in the lower section.

In buildings with towers projecting above a relatively low and broad

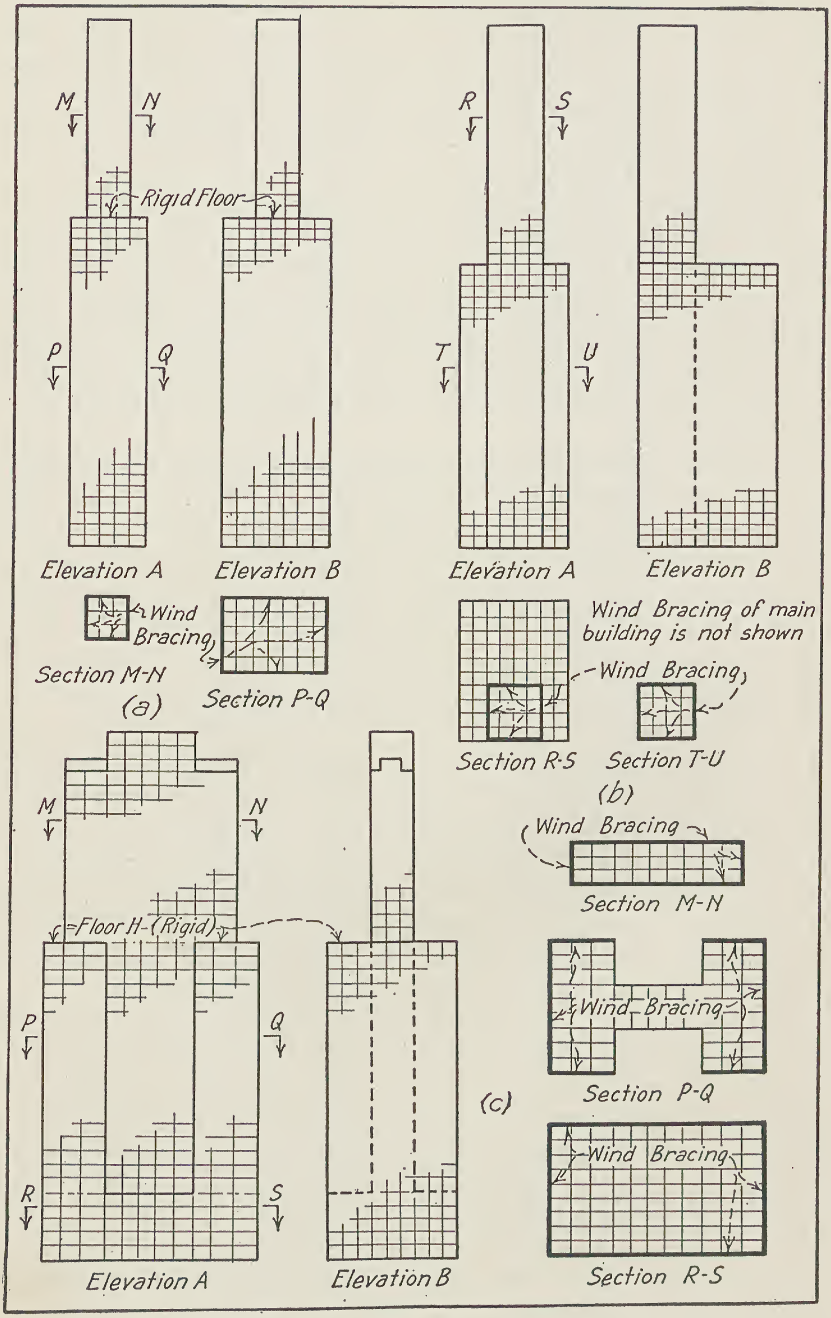



Fig. 107. Wind Bracing for Steel Office Buildings

main building the towers are usually provided with wind bracing which is independent of the main structural frame as shown in Fig. 107*b*. The tower bracing may be in the exterior bents only or in the interior bents also.

Buildings or irregular shape and buildings which change in section require special study. The system of bracing shown in Fig. 107*c* has been used on such buildings. No wind bracing is required for the upper floors. From Sections *N–N*, *P–Q* and *R–S* it is seen that the wind bracing is all placed in the outside walls but all outside walls do not contain wind bracing. The horizontal thrust on the portion of the building above Floor H is transmitted to the wind bents in the outside walls below Floor H. In order to transmit this horizontal thrust Floor H must be specially designed. The vertical wind loads in the columns above Floor H are transmitted directly down the same columns below Floor H.

**Joint Details.** — Various types of joints between wind girders and columns are illustrated in Figs. 108*a* to *f*. The simple connection in Fig. 108*a* may be used when the moment is small. It can be used on interior connections as well as exterior connections as it does not occupy any space. The connection shown in Fig. 108*b* will develop considerable resisting moment and occupies very little space. The connecting members are I-beams or H-beams with one flange cut off.

A framed connection can be used with this detail in place of the seated connection shown. The connection shown in Fig. 108*c* is extensively used. The brackets are I-beams which have been cut diagonally. A triangular plate and a pair of angles can be substituted for each I-beam bracket and a plate girder can be substituted for the I-beam. The connection shown in Fig. 108*d* can be used to develop large resisting moments. A single plate is used to form both brackets and replace a part of the web of the girder. This requires the use of splice plates as shown. The connection shown in Fig. 108*e* is similar to that in Fig. 108*d* except that stiffener angles are provided along the edges of the bracket to prevent buckling. Conditions may not permit the use of a top bracket. In this case the detail shown in Fig. 108*f* may be used. This connection to the column is different in this detail than that shown in the other figures but the two connections can be interchanged on all of the types. Several methods used in connecting this type of connection to a column are shown in Fig. 108*f*. The connections shown in Fig. 108*d* and 108*e* can be altered so as to have a bottom bracket only to correspond with the connection in Fig. 108*f* and all three types may be changed so as to have top brackets instead of bottom brackets.

In tall slender buildings the wind moment may place tension in some

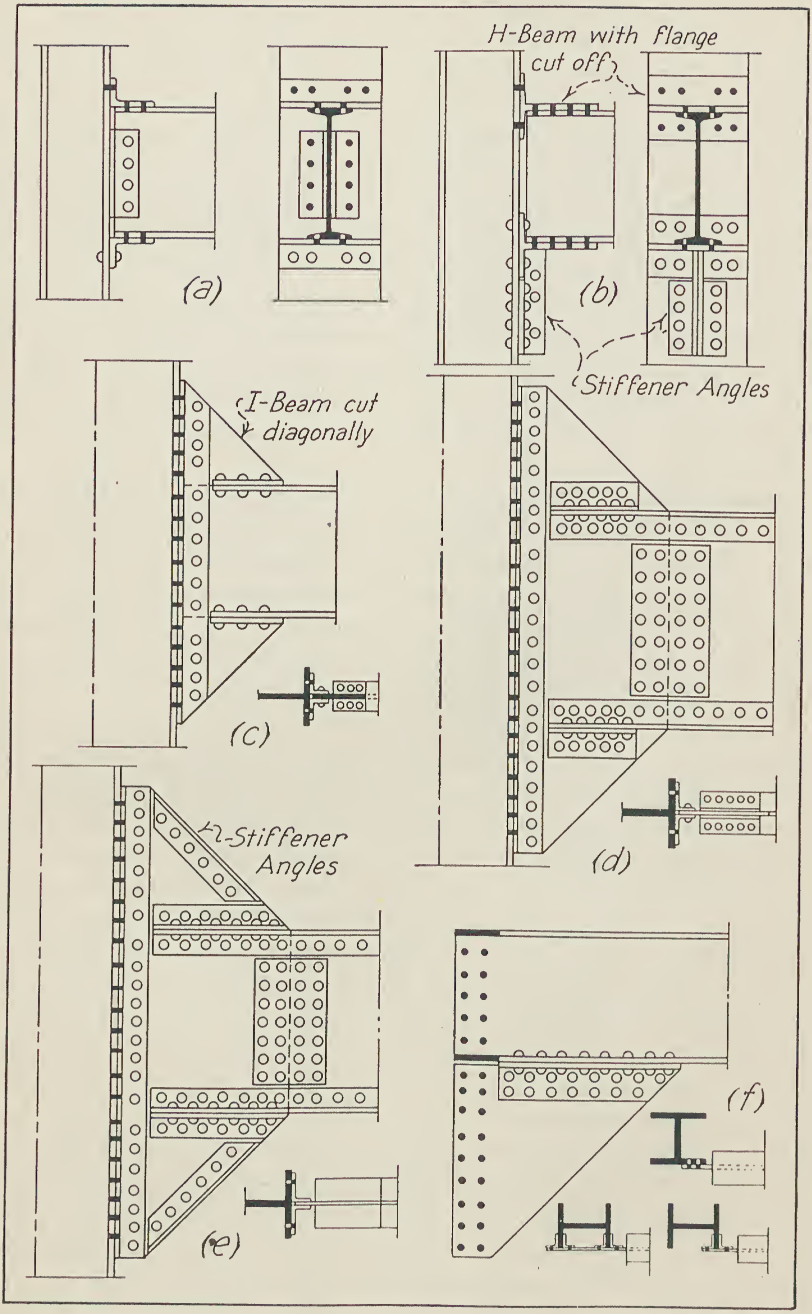



FIG. 108. Wind Bracing Details

of the columns. These stresses must be provided for in the design of the column splices and in anchoring the columns to the foundations.

The various methods which have been used for wind bracing of tall steel buildings are shown in Fig. 109. The method which has been explained in detail in this article is shown in Fig. 109*a*. Knee-braces as shown in Fig. 109*b* were used above the 28th floor of the tower of the Woolworth Building in New York City and the solid portals as shown in Fig. 109*d* were used in the tower below this floor. A modification of the diagonal bracing shown in Fig. 109*e* was used in the Singer Tower.

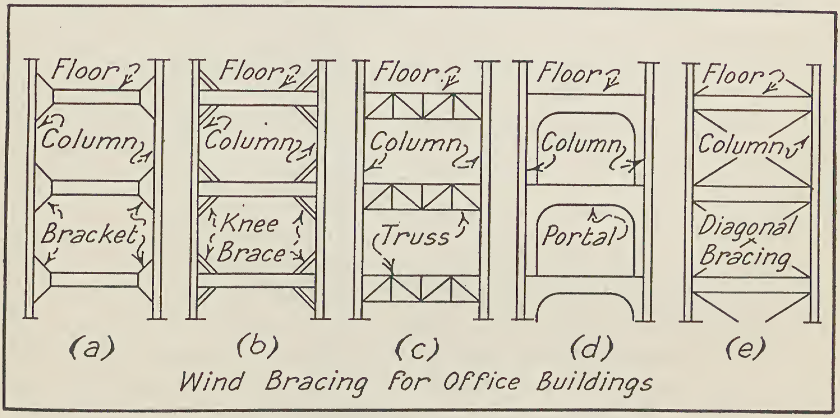



Fig. 109. Various Types of Wind Bracing

**Earthquake Resistance.** — The stresses produced by earthquake shocks are proportional to the weight of a building and its contents and not to the surface area as in the case of wind stresses so the assumption that a building designed to resist wind loads will also resist earthquake shocks is without foundation. As stated in Article 3, a wind load of 30 lb. per square foot of exposed wall area is considered adequate to resist the most severe wind storms. In areas subject to earthquake shocks, an authoritative requirement for buildings on good foundations is a lateral load equal to $7\frac{1}{2}$ per cent of the weight of the building and contents. The weight of fireproof buildings of skeleton steel construction is about 20 lb. per cu. foot. The lateral force required for satisfactory earthquake resistance is therefore $.075 \times 20 = 1\frac{1}{2}$ lb. per cubic foot. This would equal the wind load requirement for a building with a horizontal dimension of only $30 \div 1\frac{1}{2} = 20$ ft. measured in the direction of the wind. For a building 50 ft. wide the lateral force required to resist earthquake shocks under the conditions given would correspond to $50 \times 1\frac{1}{2} = 75$ lb. per sq. ft. or exposed wall area. Such loads have a pronounced influence on the design of buildings.

In an article in the Engineering News-Record Henry D. Dewell gives the following fundamental principles of design:[1]

Certain essential features of earthquake-resistant construction which are generally recognized by those who have given study to the subject will be set forth. These are applicable to all types of buildings.

*Location.* — Disadvantageous locations are (1) proximity to an active fault plane, (2) made or marshy land and (3) the junction between soils which would act differently in an earthquake shock, as the top of a bluff or the bottom of a slope. Conversely, a location at some distance from the active fault plane, and on hard rock or good firm deep soil, with approximately level surface, is most advantageous.

*Shape of Building.* — The building that is "closed" in plan, as a hollow or solid rectangle, is best from the standpoint of seismic risk. Buildings of L or U shape are at a disadvantage in an earthquake, for the component parts would likely have different vibration periods, resulting in heavy stresses at the junction of the parts. Finally, uniformity as opposed to irregularity of height is a desideratum.

*Foundations.* — Deep foundations are a valuable asset in an earthquake. Foundations should be substantial in design and well tied together. All concrete foundations should be well reinforced, and the reinforcing from one unit should be carried well into connecting units. High soil pressures should be avoided, and particular attention should be given to the corner piers, to give them ample bearing area against the earthquake effects which are there concentrated.

*Superstructure.* — The superstructure should be built to give, in effect, a unit mass against earthquake. Rigidity is essential. Full diagonal bracing should be used when possible, and deep knee-bracing when openings will not permit full diagonals. The walls should be carefully designed, heavily reinforced around openings, which should be as few as possible. Solid panels on either side of a corner add great resistance to the wall. Veneers of stone or brick should be avoided, but if absolutely necessary should be thoroughly tied and anchored to a rigid backing.

*General.* — Buildings with towers or heavy cornices and buildings with very unequal distribution of mass are at a decided disadvantage in an earthquake. The various units, having different natural periods of vibration, tend to batter against one another; the result is almost certain destruction, unless these units are properly framed to resist such action.

Buildings or parts of a building that are in contact but not bonded firmly together may sway with different periods. In that case they are likely to separate and come together again with some degree of violence, sufficient to destroy them. It is therefore important that structures should be symmetrical in design and in distribution of weight. Where that ideal is impracticable, the unsymmetrical sections should be firmly tied together so that they will swing as a unit, or else they should be separated beyond the range of collision and connected (where

[1] Earthquake-resistant Construction. Engineering News-Record, Vol. 100, p. 699.

connection is necessary) only by lighter and more fragile structures in which damage may be safely and economically concentrated.

The following recommendations made by Dr. T. Naito of Waseda University, Japan, are quoted in Mr. Dewell's article:

(1) That reinforced-concrete walls, particularly with diagonal reinforcing, be used when possible; (2) that the corner bays of buildings have as few openings as possible; (3) that the full depth of wall spandrel sections be utilized as beams; (4) that structural steel wall columns of I and H shape have their webs always placed parallel with the walls; (5) that end restraint additional to that furnished by their connections to columns be given the beams on column center lines, by means of extra reinforcing bars in the concrete floor slab across the column; (6) that horizontal diagonal bracing be used between the floor beams attaching to an interior column; (7) that particular attention be given the corner wall columns of a building, because such columns act as flanges of the vertical cantilever beams represented by the walls, and hence will carry heavy direct stress in an earthquake; (8) that for a similar reason, ample area to carry these column loads be given the footings of such corner columns, and (9) that foundation footings be well tied together.

**Steel Frame.** — The frame of a building of the office building type formed by assembling the various beams, girders, and columns is illustrated in Fig. 110. In this frame no special provision has been made for wind bracing. The following points should be noted:

1. The outside wall, called a panel or inclosure wall, is supported at each story by the spandrel beams which transmit their load to the outside columns.

2. The panel walls shown are veneered with stone ashlar $3\frac{3}{4}$ in. thick which is bonded to the backing by a bond course $7\frac{1}{2}$ in. thick every third course and by anchors which are provided at the intermediate joints. The backing may be of brick or of hollow tile. The anchors are galvanized after bending. One bond course rests on the spandrel beam.

3. The floor-beams are placed at the third points of the girders where they cause the least moment. They are connected to the girders by framed connections.

4. The floor-beams are attached to the columns by seated connections. Framed connections can be used if there is room to get them in.

5. Framed connections are used between the girders and columns. Seated connections can be used if the stiffener angles can be small enough so that they will not project through the fireproofing.

6. Constant-depth H-section columns are used. The columns are continuous through two stories. Sometimes columns continuous for three stories are used.

7. The column splices are located about 2 ft. above the floor.

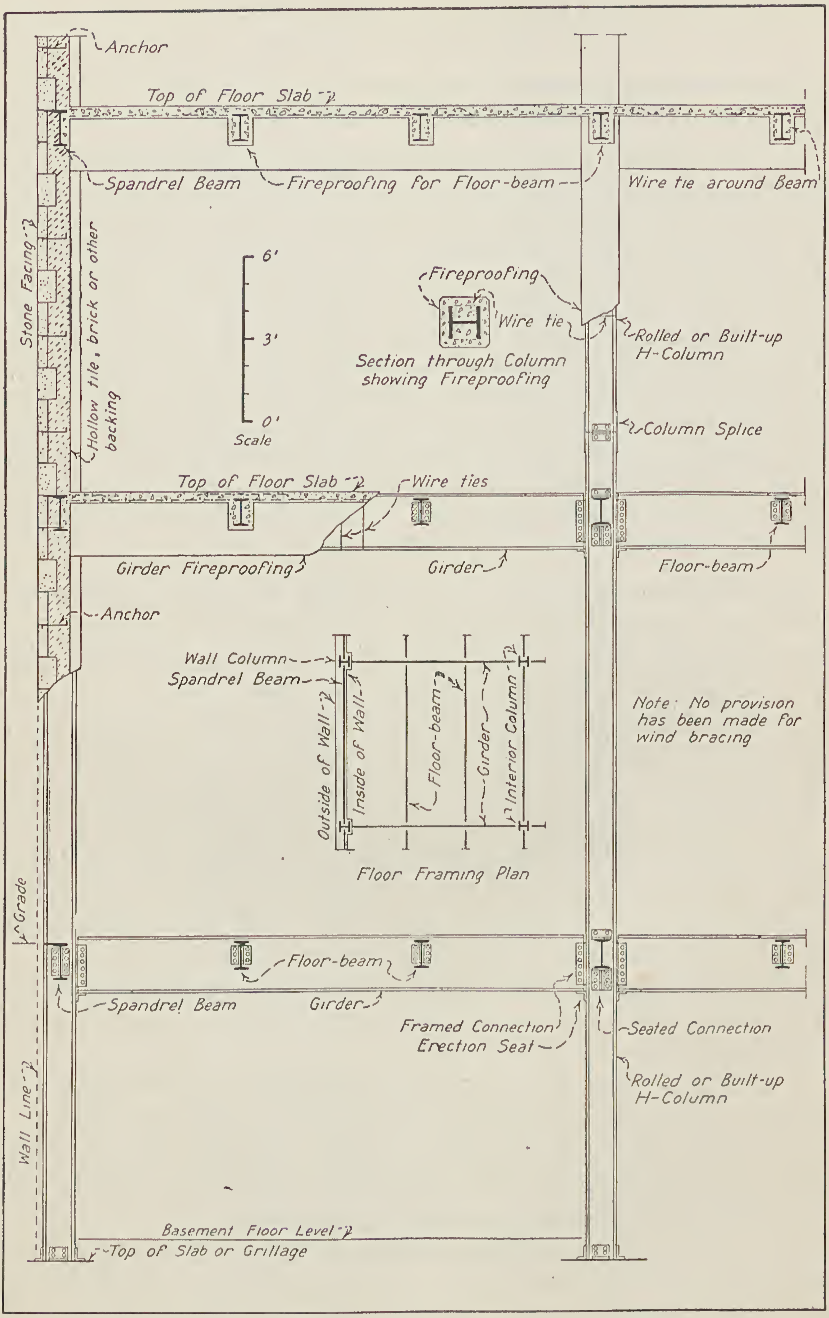



FIG. 110. Office Building Construction

8. Reinforced-concrete floor slabs supported by steel beams are shown. Many other types of floor, as described in Article 46, might have been used.

9. The supports for the columns is not shown. The columns would rest on slabs or grillages which would spread the column load over concrete footings or piers.

10. All steel members are fireproofed.

**Typical Framing Details.** — Typical details of office building construction are shown in Fig. 111*a*. The points which should be noted are:

1. The column is a built H consisting of four flange angles, a web plate, and two cover plates.

2. A built-up base is shown but slab bases as shown in Fig. 103*l* are more commonly used to distribute the column load.

3. Framed connections are shown between the floor beams and the girders.

4. Seated connections and framed connections are shown between the girders and the column. Either type might be used if there is sufficient clearance.

5. Erection seats are provided on the columns, when framed beam or girder connections are used. These seats are provided to support the beams or girders while temporary bolts are put in some of the rivet holes to hold the beams or girders in place while the first rivets are being driven.

6. Countersunk rivets are used in some places directly opposite the beams and girders so that they can be swung into place during erection. If button heads had been used these beams and girders could not be placed for the rivet heads would interfere. In some cases the rivets are countersunk on the near side to provide clearance for the girder which is on the near side of the column. In other cases the rivets on the far side are countersunk to provide clearance for the girder on the far side.

7. The clip angle on the top flange of girders with seated connections is not shop-riveted to the girder or to the column but is field-riveted after the girder is in position. This procedure is followed for two reasons. If the clip angle were riveted to the column it would be difficult to place the girder when the connection is to the column flange and impossible to place it if the connection is to the column web. . Girders are cut a half-inch or more short of the clear distance between columns. This is done because of the greater cost of more accurate cutting and because it provides clearance when placing the beam if the clip angles are not riveted to the flange of the beam. If the clip angles were riveted to the top flange the distance between the backs of the clip angles on the two ends would have to equal the clear distance between the columns and no clearance would be provided. This condition exists in the case of framed connections.

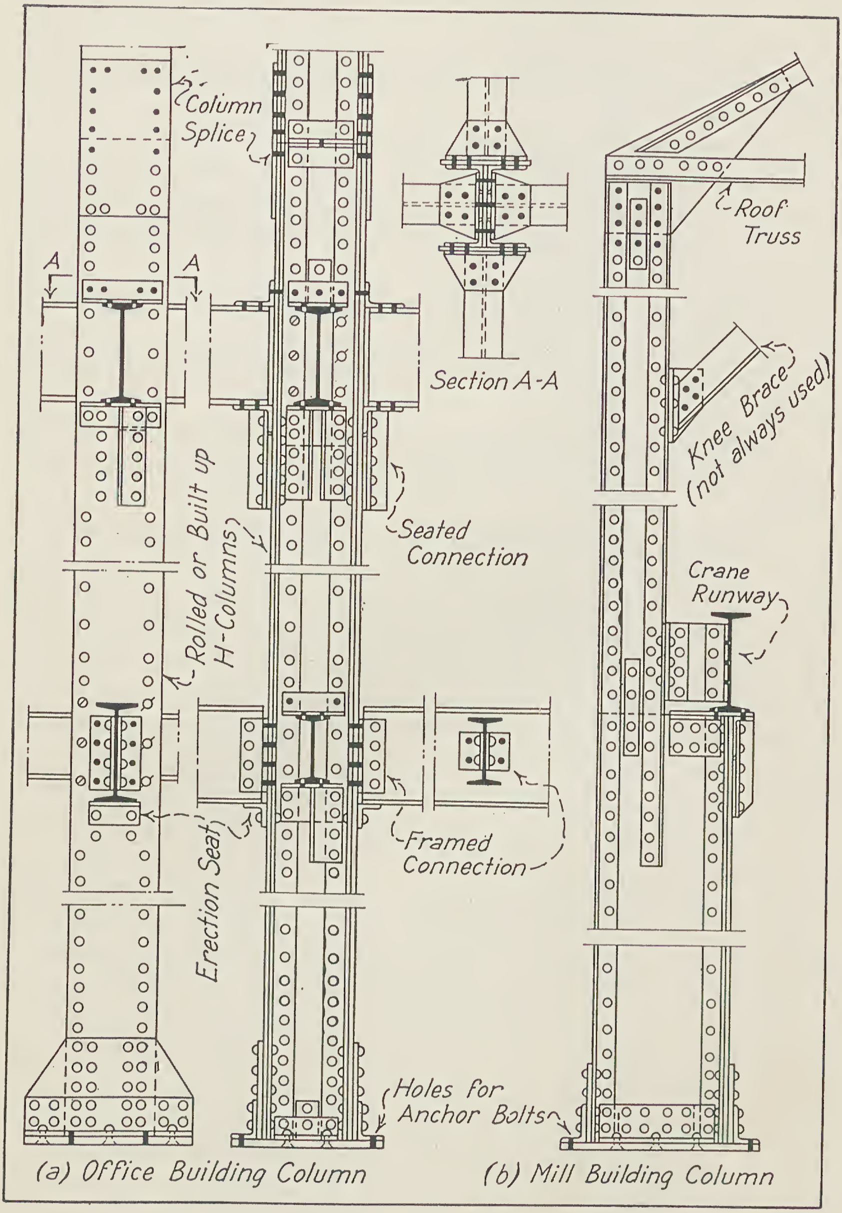



FIG. 111. Steel Column Details

8. The column extends through two stories as is customary and is spliced about 2 ft. above the floor line.

9. The ends of the abutting columns are surfaced accurately by milling so that they get good bearing. The column stress is transmitted directly across the cut section by bearing. The splice plates serve only to hold the members in line.

10. Field rivets are provided in the splice plate and column just below the top of the column. This is done to permit the splice plates to be spread slightly when placing the upper column section.

Typical details of a mill building column are shown in Fig. 111*b*. The points which should be noted are:

1. The offset in the columns is to provide for the support of the crane runway. If the building were not provided with a crane, the column section would be constant.

2. The crane runway is centered over the inner flange of the lower section of the column. This is common practice but is not essential.

3. A knee-brace is shown to resist the lateral forces due to wind and to the thrust of the crane when accelerating transversely while carrying a load or the thrust due to the lateral swinging of a load. Knee-braces may be omitted if other lateral bracing, as shown in Fig. 105, is provided. If headroom is a determining factor, a design without knee-braces would probably be used for such braces must be sufficiently high to clear the crane.

4. Field rivets are provided just below the junction of the web plate of the column and the gusset plate of the roof truss. This enables the flange angles to be spread slightly to permit the gusset plate to enter.

**Fireproofing Structural Steel Members.** — In buildings classed as fireproof or fire-resistive it is necessary to protect steel, columns, girders, beams, etc., from becoming heated to such a degree that they will loose their strength and fail. According to data quoted in Steel Construction published by the American Institute of Steel Construction the elastic limit and ultimate strength of steel of the ordinary structural grade decreases about 5 per cent at about 250 deg. fahr. From this temperature to about 700 deg. fahr. the elastic limit and ultimate strength increase and at 700 deg. fahr. the ultimate strength is about 20 per cent greater than at ordinary temperature. Beyond 700 deg. fahr. both the elastic limit and ultimate strength decrease very rapidly; at 900 deg. fahr. they are about the same as at ordinary temperature but at 1200 deg. fahr. they are only about one-third of their strength at ordinary temperatures. In ordinary fires temperatures of 700 deg. fahr. are frequently reached and in severe fires temperatures of 1700 to 2000 deg. fahr. are developed. Considering these conditions it is necessary to provide protection for

structural steel members of fireproof buildings so that they will not become excessively heated.

The following provisions for the fireproofing of structural members are quoted from the Minimum Requirements for Protected Steel Construction included in the Specifications for Standard Industrial Buildings prepared by the Committee on Building Construction of the National Fire Protection Association.[1]

The purpose of fireproofing is to insulate metal members against a rise of temperature that would seriously impair their strength and usefulness. The ideal method of stipulating requisite protection of steel against the effects of fire would be to express in terms of time, the insulation which should be afforded. Since, in the present state of the art, sufficient information is not available as to the insulating value of various building materials, the following provisions are expressed in terms of thickness based upon the best current knowledge of performance of the stated materials.

*General Provisions.* — All metal structural members which support loads or resist stresses shall have a protection of fireproofing as herein specified. The protection material shall be of brick, concrete, hollow building tile, or gypsum, conforming to the provisions of General Requirements.

Plaster shall not be considered a part of any required fire proofing for metal structural members in standard fire-resistive industrial buildings except as provided under Interior Columns.

The extreme outer edges of lugs, brackets, and similar supporting metal may project to within one inch of the outer surface of the protection hereinafter specified.

Poured-in-place concrete or gypsum protection for all structural members shall be reinforced by suitably spaced and designed steel anchors not less than $\frac{1}{8}$ in. in thickness if flat or number 12 gage if of wire.

Brick or blocks used for fireproofing shall be accurately fitted and bonded and have all spaces between the fireproofing casing and the metal solidly backfilled (without voids) with mortar, with masonry laid in mortar, or with concrete.

Fireproofing of metal structural members shall not be integral with abutting non-bearing walls but may lend lateral support by being tied or anchored thereto without incorporation with the same.

All brick or blocks used for fireproofing shall be set in Portland cement mortar, except that gypsum blocks shall be set in gypsum mortar.

No pipes, ducts or wires shall be placed within the area required for fireproofing. This provision is not to preclude the use of inserts or conduit outlet boxes in the fireproofing casing.

*Protection of Wall Columns.* — All columns which support steel girders carrying exterior walls, and all columns which are built into walls and support floors only, shall have protection against corrosion and be encased in a casing of brick masonry not less than $3\frac{3}{4}$ in. thick or not less than 3 in. of concrete; all to be well bonded or anchored into the masonry of the encasing walls.

[1] Proceedings of 22nd Annual Meeting, p. 245.

*Protection of Wall Girders.* — Wall girders shall have the same protection as required for all wall columns except that the extreme outer edge of the flanges of beams, or plates or angles connected to the beams may project within 2 in. of the outside surface of such casing. The inside surfaces of the girders shall be similarly protected by masonry, or if projecting inside the walls, they shall be protected by concrete, hollow building tile, gypsum, or other approved fireproofing materials not less than 2 in. thick.

*Interior Columns.* — Interior columns shall be inclosed in a continuous casing of fireproofing, which shall cover the columns at all points to a thickness of not less than 3 in., except that non-siliceous poured concrete or cast-in-place gypsum may be not less than 2 in. thick.

When aggregates showing an expansion under temperature materially greater than that of limestone or trap rock are used the fireproofing shall be 1 in. thicker and shall be reinforced with metal mesh or in lieu of additional thickness may be covered with expanded metal or wire lath and cement or gypsum plaster 1 in. thick.

Block column covering shall be securely anchored to steel with approved anchors or ties, or additional bond shall be provided for stability by the use of metal fabric reinforcement in horizontal joints. Galvanized tie wire, not less than No. 12 gage, may be tightly bound around each course of blocks when column casing is plastered or in sprinklered buildings, unplastered.

Columns subject to moisture and corrosion shall be adequately protected before application of fireproofing.

Concrete filled steel or wrought-iron pipe columns shall be protected by not less than $1\frac{1}{2}$ in. of fireproofing.

Where subject to mechanical injury from trucking or handling of merchandise fireproofing shall be protected by suitable jacketing.

*Protection of Steel Girders, Beams and Trusses.* — The webs and bottom flanges of interior girders and trusses shall be protected with fireproofing not less than 2 in. thick at all points. Beams, lintels, and all other structural members, except roof trusses and roof purlins shall be similarly protected with fireproofing not less than $1\frac{1}{2}$ in. thick.

If hollow building tile or gypsum block are used for protection, the lower flanges of beams and similar members shall be encased with self-anchoring and well bonded solidly mortared skew backs or soffit fillers.

Steel angle or channel struts, or other minor structural framing not elsewhere provided for, which are used for support in any wall, partition, or other construction, shall be protected by not less than 1 in. of expanded metal or wire lath and cement or gypsum plaster.

Unless protected as for girders, roof trusses shall be boxed in with metal fabric having large mesh and wholly encased in expanded metal or wire mesh and cement or gypsum plaster not less than 1 in. in thickness, furred off from the bottom chord 1 in.

The Uniform Building Code of The Pacific Coast Building Officials Conference uses the time requirement for specifying the protection which is to be provided as follows:

Minimum Protection of Structural Parts Based on Time Periods for Various Incombustible Insulating Materials

| Structural parts to be protected | Insulating material used | Minimum thickness of material in inches for the following fire-resistive periods | | | |
|---|---|---|---|---|---|
| | | 4 hr. | 3 hr. | 2 hr. | 1 hr. |
| Steel or cast-iron columns; Projecting steel beam and girder flanges; Top and bottom chords and all primary truss members | Grade A concrete | 3 | 2 | 1½ | 1 |
| | Grade B concrete | 4 | 3 | 2 | 1½ |
| | Gunite | 2½ | 1½ | 1 | ¾ |
| | Brick of clay, shale, concrete or sand-lime | 4 | 4 | 2½ | 2½ |
| | Clay tile, or clay tile and concrete | 4 | 3 | 2 | 1½ |
| | Solid gypsum blocks | 4 | 3 | 2 | 1½ |
| | Metal lath and gypsum or Portland cement plaster | 3 | 2½ | 2 | 1 |
| Webs of steel beams and girders | Grade A concrete | 2½ | 1½ | 1 | 1 |
| | Grade B concrete | 3½ | 2½ | 1½ | 1 |
| | Gunite | 2 | 1 | ¾ | ¾ |
| | Brick of clay, shale, concrete or sand-lime | 4 | 2½ | 2½ | 2½ |
| | Clay tile, or clay tile and concrete | 3 | 2 | 1½ | ¾ |
| | Solid gypsum blocks | 3 | 2 | 1½ | 1 |
| | Metal lath and gypsum or Portland cement plaster | 2½ | 2 | 1½ | ¾ |

Methods of fireproofing steel columns are given in Fig. 112*a* to *d* and steel beams in Fig. 112*e* to *h*. Many building codes do not require that roof trusses, roof beams and purlins, supporting roof loads only, be fireproofed if the clear distance between trusses and the floors which they span is over 20 ft. Some codes require that the roof trusses be protected with an incombustible ceiling below their lower chords and others permit the trusses to be exposed from below. All other trusses in fireproof buildings should be fireproofed. The specifications of the National Fire Protection Association, just quoted, require that roof trusses be fireproofed.

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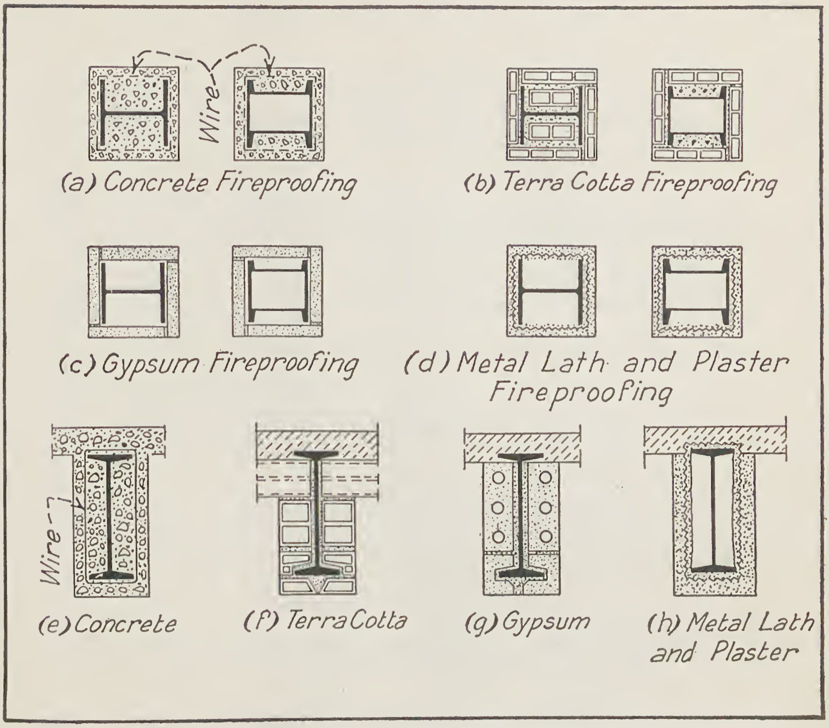



Fig. 112. Methods of Fireproofing Steel Members

## ARTICLE 40. STEEL-STUD PARTITIONS AND CORRUGATED SIDING

**Metal Lath on Metal Studs.** — Hollow partitions may be made by wiring metal lath to both sides of steel studs 12 to 16 in. apart and covering with plaster as shown in Fig. 113*a*. The various forms of metal lath are described in Article 79. The common form of hot-rolled structural channels is too heavy and therefore too costly to use for studs whose depth is over 1 in. Special cold-formed channels made of sheet steel bent to form the channel section are usually used. They may be obtained provided with prongs for holding the metal lath as shown in Fig. 113*b*. The common depths of cold-formed channels used for hollow partition are 2, 3 and 4 in. Studs are obtainable which are built up of two $\frac{3}{4}$-in. channels fastened together at intervals as shown in Fig. 113*c*. This form of construction is illustrated in Fig. 113*d*. Partitions with metal studs and metal lath are more expensive than other forms using wood lath or studs but are incombustible and fire resistant to a high degree.

Exterior walls sometimes use this type of construction in which case the outer surface is back-plastered.

This type of construction may be used for bearing walls or partitions for light loads.

**Metal Lath and Plaster Solid Partitions.** — Solid partitions $1\frac{1}{2}$ in. or 2 in. thick are constructed of studs of $\frac{3}{4}$-in. or 1-in. channels, spaced $11\frac{3}{4}$ or

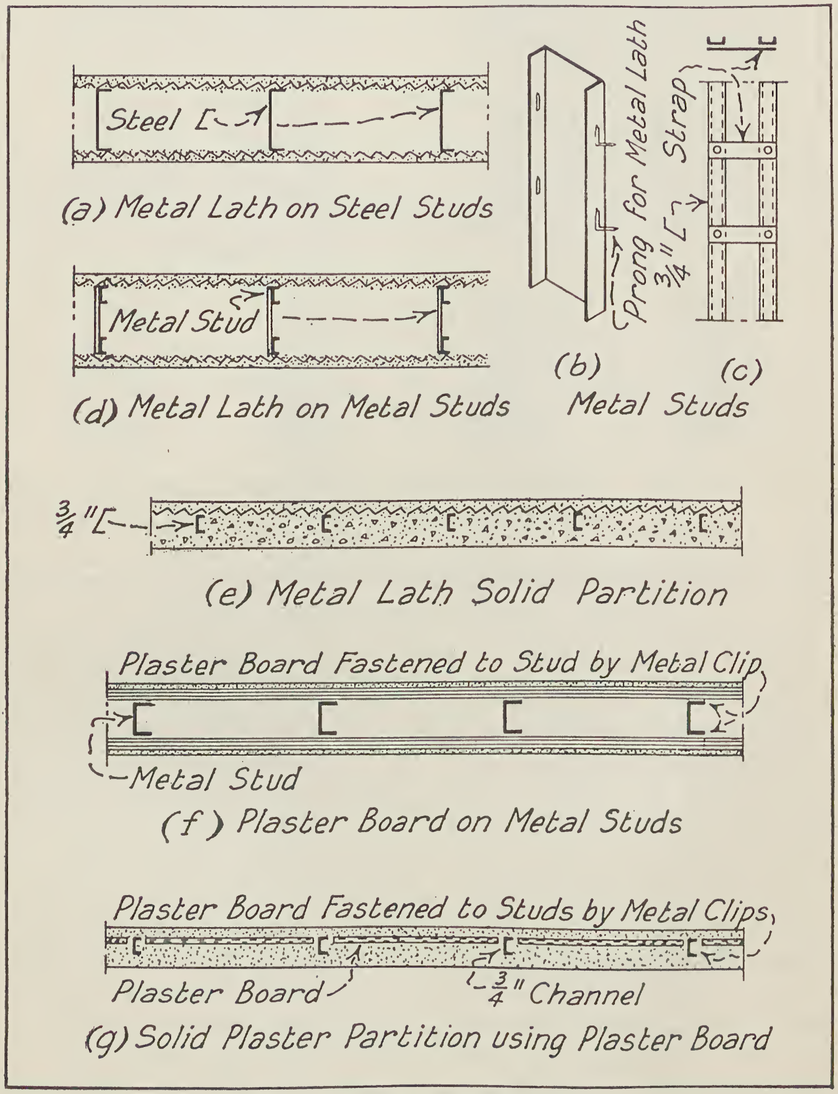



FIG. 113. Steel Stud Partitions

$15\frac{3}{4}$ in. to allow for end lap, to which metal lath is wired on one side and plaster applied on both sides as shown in Fig. 113*e*. The metal lath is placed with its greatest dimension horizontal; sheets are lapped at least

$\frac{1}{2}$ in. on the sides and wired together at one point between the studs; sheets are lapped at least 1 in. on the ends and are wired at 6-in. intervals along the stud. The channels are held in place by springing into holes drilled into the floor and ceiling in concrete construction. On wood floors the channels are bent to an angle and spiked. Integral lath may be used instead of the ordinary lath and channel studs.

This is an excellent form of fire-resistant partition and requires the least floor space of any type of partition. It is also used for outside curtain walls in some cases. This type of construction is not used for bearing partitions.

The Uniform Building Code of the Pacific Coast Building Officials Conference contains the following clauses relating to non-bearing partitions of plaster on metal lath and studs:

Solid or hollow non-bearing partitions of reinforced plaster shall have a thickness of not less than 1/60 of the unsupported height, but never less than $1\frac{1}{2}$ in. for solid partitions nor have a shell thickness of less than $\frac{3}{4}$ in. for hollow partitions. Such partitions shall have vertical steel of iron channels with a depth of not less than one-half the thickness of the partition, made of not less than No. 20 U. S. gage metal spaced not more than 24 in. apart.

If gunite is used instead of plaster applied in the ordinary way the minimum ratio of thickness to height permitted by this code is one-seventieth. Gunite is defined as "a mixture of Portland cement and fine aggregate mixed dry, passed through a cement gun, hydrated at the nozzle and deposited under pressure in its place of final repose."

**Plaster Board on Metal Studs.** — Hollow partitions may be made by plastering on plaster board fastened to both sides of metal studs spaced 12 to 16 in. apart, and of the forms described in the paragraph on partitions of metal lath on metal studs. This type of construction is illustrated in Fig. 113*f* and is used only for non-bearing partitions.

**Solid Plaster Partition Using Plaster Board.** — Solid partitions 2 in. thick may be made by plastering both sides of plaster board fastened, by special clips, to $\frac{3}{4}$-in. or 1-in. hot- or cold-rolled steel channel studs spaced $24\frac{3}{4}$ in. apart as shown in Fig. 113*g* and securely fastened to the floor and ceiling. This type of construction is not used for exterior curtain walls nor for bearing partitions.

**Corrugated Siding.** — Corrugated steel is extensively used for the side walls and roofs of steel mill buildings. Corrugated zinc, asbestos board, and glass are used to a limited extent. All of these materials are described in Article 61. The methods used in fastening corrugated steel and zinc to steel girts to form the side walls of mill buildings are illustrated in Fig. 114. In Figs. 114*a* and 114*b* nails are driven through the tops of the corrugations and clinched around the angle or channel girt.

In Figs. 114*c* and 114*d* a metal clip is bolted to the siding and catches over the girt, the detail shown in 114*d* being used for corrugated asbestos board also. In Fig. 114*e* a metal strap passes around the girt and is fastened to the siding at points above and below the girt. In Fig. 114*f* the siding is nailed to a nailing strip bolted to the back of a channel girt.

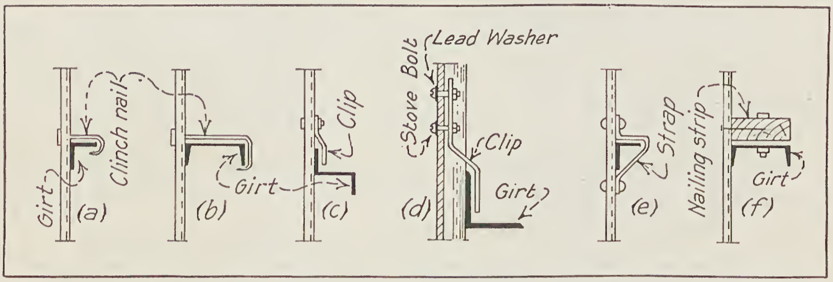



FIG. 114. Methods of Fastening Corrugated Siding

This type of construction is inexpensive but buildings covered with corrugated metal are difficult to heat in winter, they are hot in summer and are unattractive. Condensation of the cold surface of the metal may cause trouble in which case anti-condensation lining as described in Article 61 may be used.

# CHAPTER VIII

# REINFORCED-CONCRETE CONSTRUCTION

## ARTICLE 41. REINFORCED-CONCRETE COLUMNS

Concrete columns may be divided into four classes: Columns without reinforcement; columns with longitudinal reinforcement and lateral ties spaced from 8 to 12 in. apart and surrounding the longitudinal reinforcement; columns with longitudinal reinforcement and lateral reinforcement consisting of closely-spaced hoops or spirals; and columns consisting of structural steel shapes surrounded with concrete. Columns with longitudinal reinforcement only or with lateral reinforcement only are never used.

Columns without longitudinal reinforcement are unreliable for they are easily cracked by bending stresses due to temperature changes, unequal loading of adjacent panels, or unequal settlement of footings. For this reason the use of plain concrete is confined to short columns or piers whose length does not exceed four times the least dimension.

The longitudinal rods of a column are arranged symmetrically around the edge of a column and about 2 in. from the surface. They carry from 10 to 15 times as much load per sq. in. as the concrete and reinforce the column so that it will not fail when subjected to bending stresses as mentioned above. However, if longitudinal rods are not held in position by lateral ties on hoops they will kick out and spall off the surrounding concrete. For this reason the rods must be held in line by lateral reinforcement surrounding them.

One type of lateral reinforcement consists of ties which are usually made of $\frac{1}{4}$-in. round rods as shown in Fig. 115*a*. The maximum spacing of these ties is limited by some specifications to 8 in. and by others to 12 in. or not more than 15 times the diameter of the longitudinal rods. Another type of lateral reinforcement consists of closely-spaced hoops or spirals as shown in Fig. 115*b*. Hoops are rarely used but spirals are very extensively used. The minimum amount of spirals is sometimes given as 1 per cent of the volume of the core enclosed by the spiral and sometimes as $\frac{1}{4}$ of the volume of the longitudinal reinforcement. The spacing or pitch of the spirals must not exceed $\frac{1}{6}$ of the diameter of the core with a maximum of 3 in. The minimum clear distance between the spirals is 1 in. in order that concrete may flow through the spirals, during the pouring operation, and com-

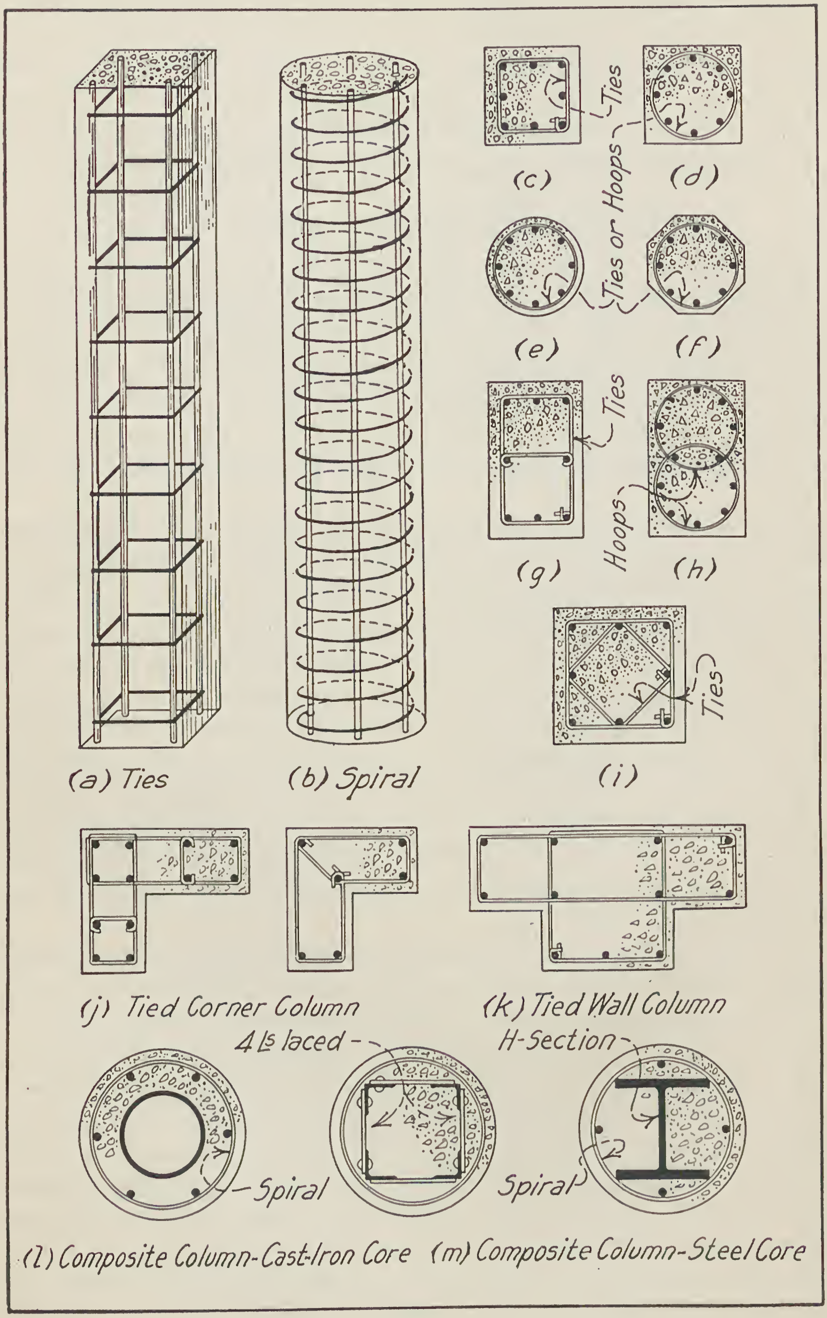



FIG. 115. Reinforced-concrete Columns

pletely fill the forms. In addition to holding the longitudinal rods in line the spirals increase the strength of a column by confining the core and make the column more reliable.

The minimum amount of longitudinal reinforcement for tied columns is usually $\frac{1}{2}$ of 1 per cent of the volume of the enclosed core but never less than four $\frac{1}{2}$-in. round rods. The maximum amount is usually stated as 2 per cent of the volume of the enclosed core.

The minimum amount of steel permitted in columns with spirals is 1 per cent of the volume of the enclosed core and the maximum 6 per cent but there must never be less than six $\frac{1}{2}$-in. round rods. The clear distance between longitudinal rods should not be less than $1\frac{1}{2}$ in.

The unsupported length of reinforced-concrete columns is commonly limited to from 12 to 15 times the least width unless special provision is made for the buckling tendency of longer columns by a corresponding decrease in the allowable unit stress. The least dimension of principal columns should not be less than 12 in. but unimportant columns extending through one story only may be as small as 6 in.

Columns may be square in section with square ties or with spirals, round in section with circular ties or with spirals, or octagonal in section with circular ties or with spirals as shown in Figs. 115*c* to *f*. The longitudinal rods are arranged around the edge of the columns and just inside of the ties or spirals which hold them in line and keep them from kicking out when the column is loaded and increase the fire resistance of the columns.

Rectangular columns are provided with one or more interior ties as shown in Fig. 115*g*, for otherwise the intermediate bars along the sides would not be adequately supported. Rectangular columns may be reinforced with overlapping spirals as shown in Fig. 115*h*. Large square columns are sometimes provided with ties as shown in Fig. 115*i*, the diagonal set of ties providing lateral support for the intermediate bars on the sides.

Corner columns are sometimes L-shaped and may be tied as shown in Fig. 115*j*. Intermediate wall columns may be T-shaped, in which case the ties may be arranged as shown in Fig. 115*k*.

The allowable unit stresses on spiraled columns is greater than that of tied columns; therefore spiraled columns are used when the loads are large and it is desired to keep the size of the columns as small as possible. Further reduction in size is accomplished by using a richer mixture in the columns than is used in the remainder of the structure. In general it is cheaper to use large columns with a small amount of steel than it is to use small highly reinforced columns. It is also economical to use rich mixtures and reduce the amount of steel.

Columns consisting of structural steel or cast-iron shapes encased in concrete, as shown in Figs. 115*l* and *m*, are commonly used. Structural steel sections held together by means of batten plates or lacing bars are preferable to solid H-sections which prevent the effective bonding of the various parts of the concrete section. Ties or spirals are used where necessary as in ordinary reinforced-concrete columns. It is desirable to provide shelves or brackets riveted to the structural section to assist in transmitting to the steel section its share of the floor loads. This type of column is called a *composite column*. It should not be confused with the steel column with concrete fireproofing in which steel floor-beams and girders are riveted to the structural steel column which is considered as carrying all of the load. Composite columns are used in the lower stories of tall buildings when it is desired to reduce the column size.

Column reinforcement should be protected against the action of fire by at least 2 in. of concrete except in the case of square columns with spiral reinforcing surrounding a circular core where $1\frac{1}{2}$ in. is considered sufficient.

## ARTICLE 42. REINFORCED-CONCRETE BEAMS AND GIRDERS

Concrete is strong in compression but weak in tension. If steel rods are placed in the concrete on the tensile side of a beam as shown in Fig. 115*a* these rods will carry the tensile stresses and a very efficient form of beam will result. A sufficient amount of steel reinforcement is used to make the beam as strong in tension as it is in compression.

The simplest form of beam is rectangular in section as shown in Fig. 115*b*, but since the concrete on the tensile side of the beam is not considered as carrying any stress some of this concrete may be left out of wide beams leaving only enough to carry the steel rods and to provide for the shearing stresses. This forms the T-beam shown in Fig. 116*c*. The outline of the corresponding rectangular beam is shown by the dotted lines. Usually some of the concrete on the compressive side near the neutral axis is also omitted as shown in Fig. 116*d*. By referring to Fig. 54*e* it may be seen that the stress carried by this material is small so that the strength of the beam is reduced only slightly by this omission.

In some cases the size of a beam is limited and it is necessary to design a beam of given strength to fit into a space which is smaller than would be required for an ordinary rectangular or T-beam. The tensile strength may be secured by providing thé required amount of tensile reinforcement but the amount of concrete which is available for compression is limited by the space to be occupied. In this case the additional compressive strength necessary is secured by placing steel bars on the compression side of the beam forming a double-reinforced rectangular beam as shown

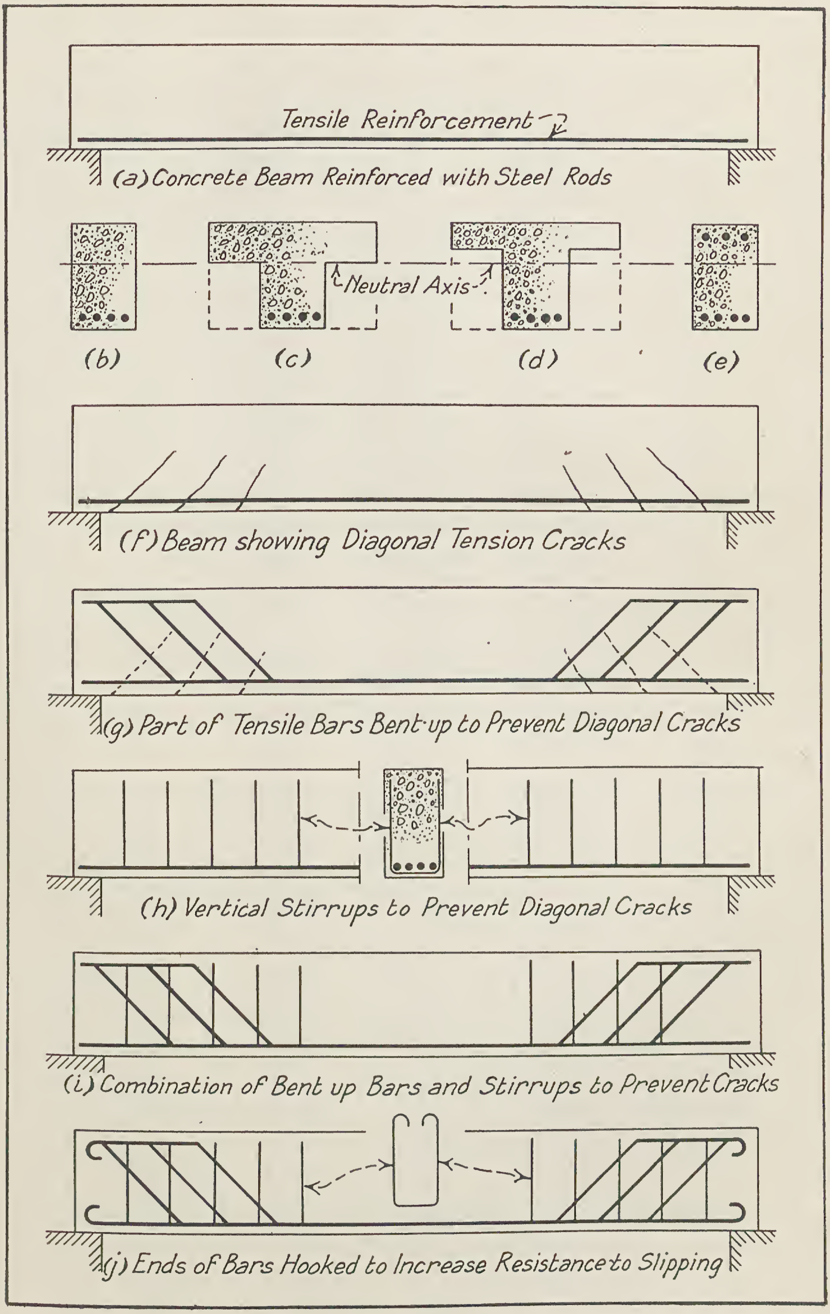



FIG. 116. Reinforced-concrete Beams

in Fig. 116*e*. A given amount of steel is about 15 times as effective in compression as the same amount of concrete; however, it is more economical to use concrete to carry compressive stresses than it is to use steel.

So far, only tensile and compressive stresses have been considered but it is necessary to provide for shearing stresses also. These stresses combined with the tensile stresses cause diagonal tension stresses which tend to cause diagonal cracks near the ends of a beam, as shown in Fig. 116*f*. Where these stresses are large it is necessary to provide reinforcement to prevent these cracks. This reinforcement may be provided by bending up a part of the tensile reinforcement as shown in Fig. 116*g* or by providing vertical U-shaped members passing around the tensile steel as shown in Fig. 116*h*. These members are called *stirrups* and should not be spaced farther apart than one-half the depth of the beam. Various other forms of stirrups may be used. In rectangular beams reinforced for compression, stirrups have the additional function of holding the compressive steel in position and overcoming the tendency of these bars to kick out. In this case the stirrups have an action similar to the ties or hoops in columns. Usually a combination of bent-up bars and stirrups is used as shown in Fig. 116*i*. The ends of stirrups should be hooked to increase their resistance to slipping. In beams reinforced for compression they are bent around the compressive steel. Steel reinforcement does not prevent the formation of cracks on the tensile side of a beam but if the steel is not overstressed the cracks are very small and are not objectionable.

Still another form of stress which must be provided for is known as bond stress. *Bond stresses* are caused by the tendency of the steel to slip in the concrete when a beam is loaded. This is frequently a serious matter. To increase the bond strength deformed bars may be used with more or less satisfactory results. The resistance to slipping may be increased by hooking the ends of bars as shown in Fig. 116*j*.

The reinforcement in continuous beams must be arranged differently from that in simple beams. If reinforcement were provided at the bottom of the beam only it is evident that the beam would crack over the intermediate supports as shown in Fig. 117*a* due to the tensile stresses which exist in the upper part of the beam at those points and if the ends are constructed monolithic with columns cracks will develop on top at or near the columns. To prevent these cracks it is necessary to provide steel near the top surface in the parts of the beam near the supports as shown in Fig. 117*b*. Instead of using separate bars at the top as shown in this figure it is more convenient to bend up some of the bars from the bottom where they are no longer needed as shown in Fig. 117*c*. At least one-third of the bars in the bottom should be left at the bottom.

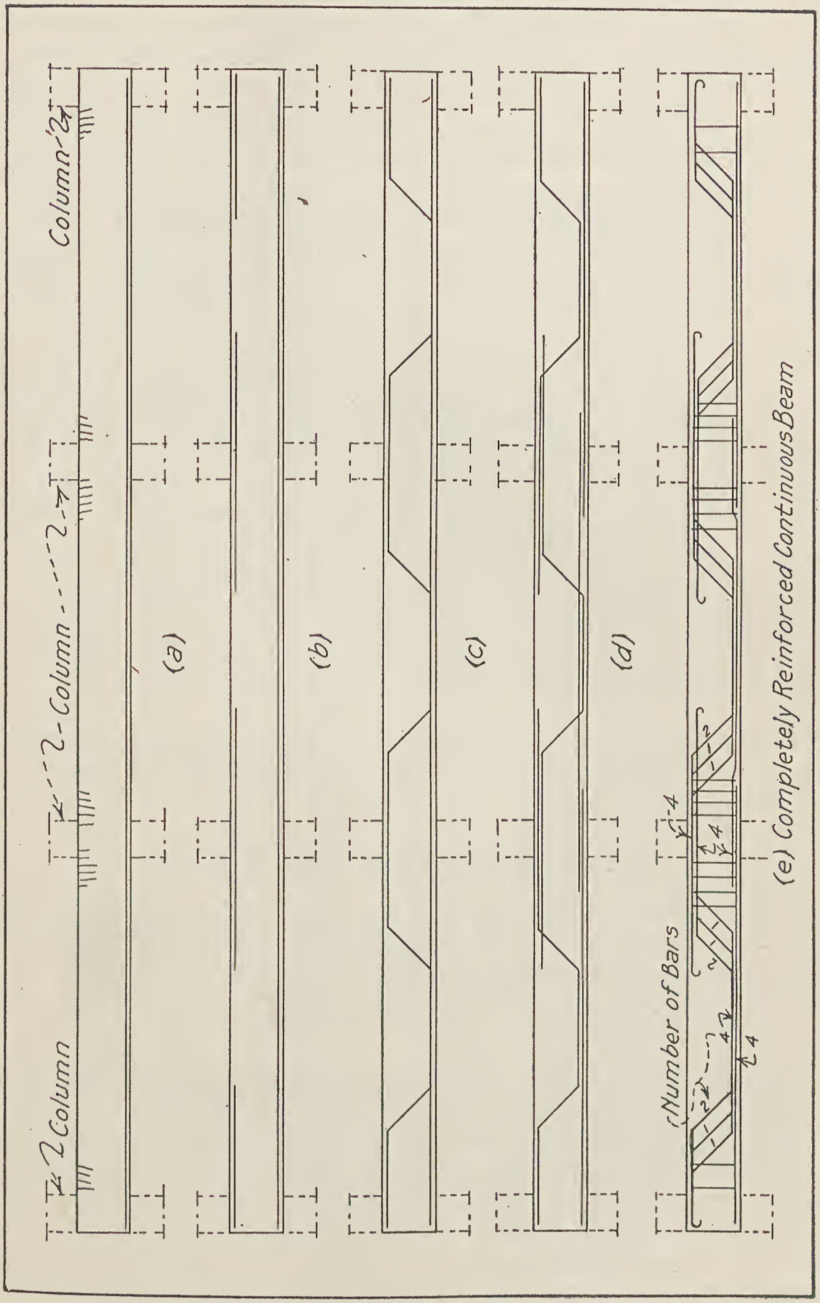



FIG. 117. Continuous Reinforced-concrete Beams

Usually the splices in the bars are made over the supports and the bars will be arranged as shown in Fig. 117*d* but not necessarily separated vertically as shown in the figure for the sake of clearness. The ends of the tensile bars are commonly hooked to increase their resistance to slipping. The inclined portions of the bent-up bars are effective in resisting diagonal tension stresses and are utilized for that purpose but it is usually necessary to use stirrups to take care of the parts of the beam where shear reinforcement is necessary that are not provided for by bent-up bars. It is desirable to bend up bars at more than one point at each end of each beam as shown in Fig. 117*e*. This figure illustrates a completely reinforced-concrete beam built monolithic with the supporting columns.

In building construction, floor slabs are commonly cast monolithic with the beams and girders as shown in Fig. 118*c*. This slab is effective in carrying compressive flexural stresses when such stresses occur in the upper part of the beam but near the supports the compressive stresses are in the lower part of the beam so that the floor slab is not effective in this capacity. At these points the bars which run straight through near the bottom of the beam are utilized to carry a part of the compressive stresses. Continuous beams which are cast monolithic with the floor slabs are therefore T-beams in the central part of the span and double-reinforced rectangular beams over the supports. See Article 43 for further discussion.

The reinforcement of concrete beams and girders should be protected against the action of fire by at least 2 in. of concrete between the bars and the surface.

## ARTICLE 43. REINFORCED-CONCRETE SLABS

**Ordinary Slabs.** — Reinforced-concrete slabs may be considered as wide shallow beams. They are used as floors and roofs of buildings with masonry bearing walls or with reinforced-concrete or steel frames. In some cases they are supported by timber beams but this type of construction is not desirable.

The simplest case is that of separate slabs supported on steel beams as shown in Fig. 118*a* but this type of construction is not common. Usually the slabs are continuous over the beams as shown in Fig. 118*b*. In this case it is necessary to provide steel near the top of the slabs over the beams because the tensile stresses are on that side at this point. This steel is provided by bending up some of the steel from the bottom of the slab. Although no tensile stresses exist at the bottom of the slab over the supports it is desirable to run about one-third of the bottom steel straight through. The amount of steel required at the top of the slab over the

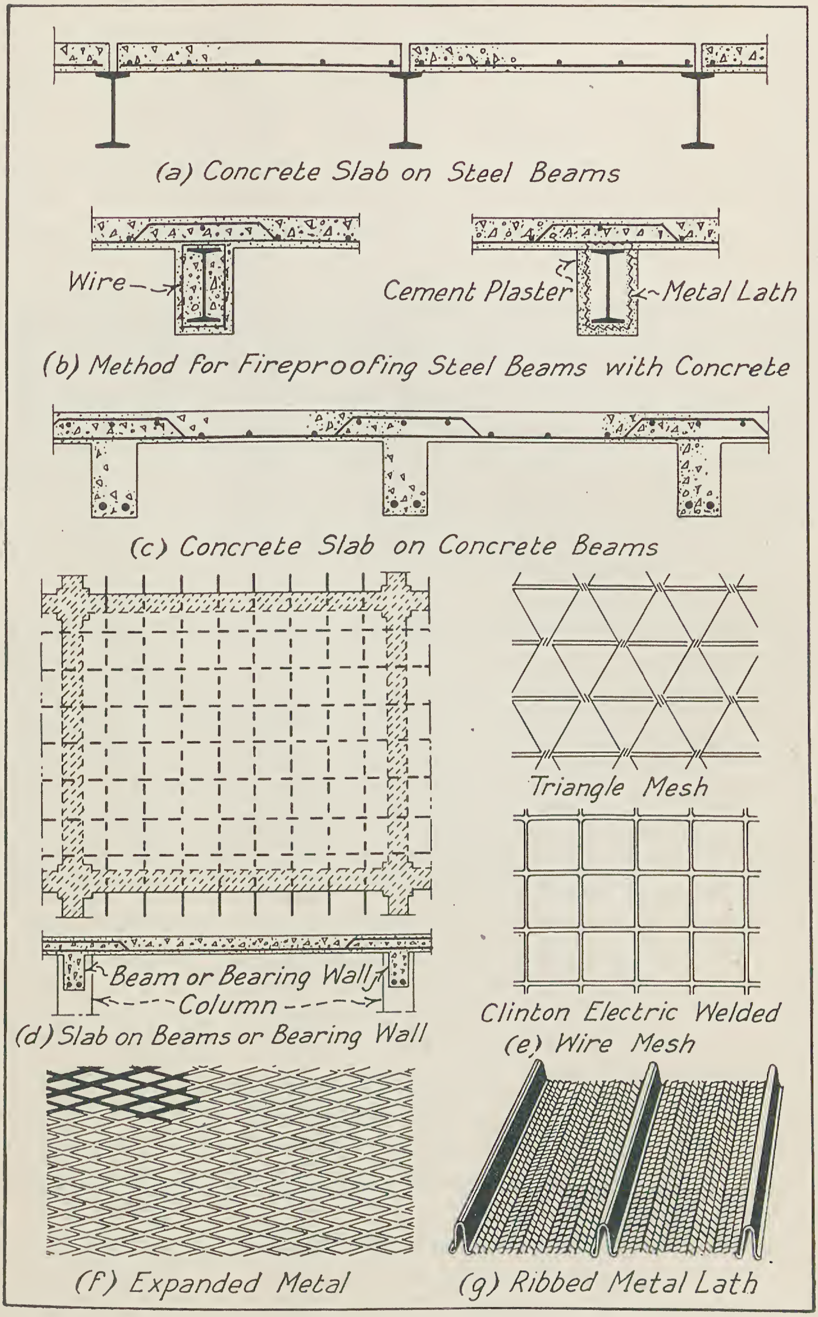


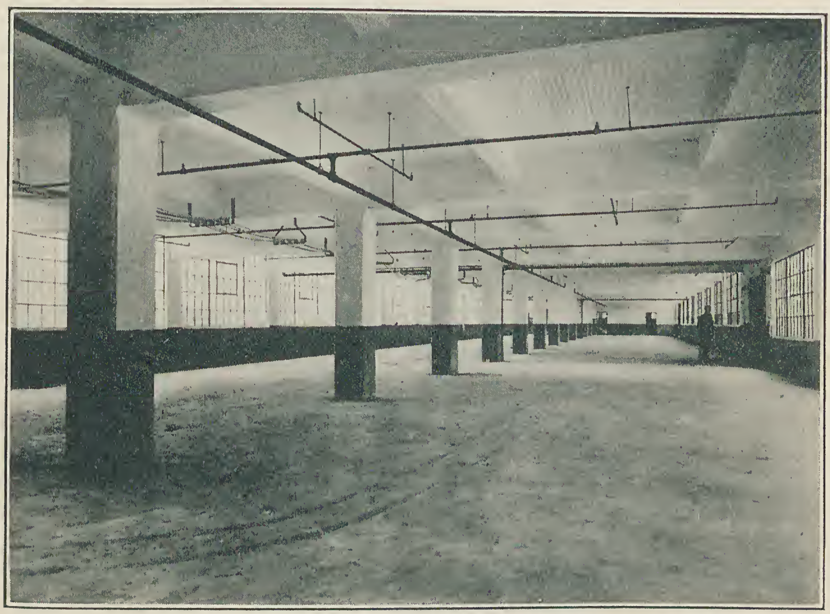

FIG. 118. Reinforced-concrete Slabs

beams is usually equal to the amount required at the bottom and in the center of the span. In buildings which are classed as fireproof it is necessary to protect the steel beams by surrounding them with concrete as shown in Fig. 118*b*. Less effective protection is provided by metal lath and plaster as also shown in this figure. See page 316.

Reinforced-concrete slabs are commonly constructed monolithic with reinforced-concrete beams and girders as shown in Fig. 118*c*. In this case, the slab serves the double function of spanning the space between the beams and acting as the flange of the T-beams which support it. The slabs are continuous over the beams and require tensile steel near the top over the beams. Specifications commonly permit the portion of the slab extending eight times its thickness each side of the beam to be considered as the flange of the T-beam. However, the total width of the slab which is so considered can not be greater than the distance center to center of beams or greater than one-fourth of the span of the beams. It is sometimes possible and desirable to support a slab on four sides by means of beams or bearing walls as shown in Fig. 118*d*. An interior view of a building with monolithic beams, girders and slabs is shown on page 336.

The principal reinforcement for slabs will, of course, run perpendicular to the supporting members but it is necessary to provide a small amount of reinforcement parallel to the supports to prevent cracks due to temperature changes and to assist in the lateral distribution of concentrated loads. The reinforcement usually consists of round or square bars but light slabs may be reinforced with some form of wire mesh as shown in Fig. 118*e* or expanded metal lath as shown in Fig. 118*f*. The ribbed metal lath shown in Fig. 118*g* is used on light slabs poured without the usual forms, the ribs being sufficiently rigid to span the distance between supports and the mesh being so fine that the concrete will not run through but is able to form a substantial grip on the mesh. A slab of this type supported on pressed steel joists is illustrated in Fig. 128. The rough lower side of the slab is concealed and protected from fire by the plastered ceiling supported on the under side of the joists. Other forms of steel joists as described in Article 36 are used in the same manner as the pressed steel joists shown in the figure. The spacing of the joists of the various types varies from 12 to 30 in. The thickness of the slab varies from 2 to 3 in. Some codes place a minimum thickness of $2\frac{1}{2}$ in. on all concrete slabs.

**Flat Slabs.** — In the slab reinforced in both directions illustrated in Fig. 118*d*, the beams running between columns on the four sides of each panel are deeper than the slab, and project below the slab. By making these beams very wide it is possible to make them the same depth as the



*Courtesy of Portland Cement Association*

REINFORCED-CONCRETE BEAM AND GIRDER CONSTRUCTION

slab, and thus obtain a flat ceiling. To carry these wide beams it is necessary to flare the columns out at the top, forming what are called *capitals*, and to further assist in carrying the load, *drop panels* are used. This type of construction is illustrated in Fig. 119*a*, and is called the *two-way system flat slab*, because the reinforcement runs in two directions. The width of the beams is usually considered as half the width of the panel, the remaining area acting as a slab supported on four sides.

In the *four-way system*, an extra set of wide flat beams is run diagonally between the columns as illustrated in Fig. 119*b*. In this system the reinforcement runs in four directions.

In both systems most of the reinforcement is near the bottom of the slab in the central part of each beam, and near the top where it passes over the drop panel and column capital. It is necessary to provide reinforcement in the top of the slab in other parts of the slab where cracks tend to form on top.

There are many other flat-slab systems, but those just described will serve to illustrate this general type of construction. An interior view of a building of flat-slab construction is shown on page 340.

Flat-slab construction is advantageous for buildings in which the panels are approximately square, where the floors are heavily loaded, where exposed beams and girders interfere with the headroom, or where it is desirable to place the tops of windows as near the ceiling as possible to secure better lighting in the building. This type of construction is particularly desirable for factories, warehouses, and other industrial buildings, but is not economical for office buildings and apartment houses where the loads are light, and is not desirable for these buildings on account of the interference of the column capitals with the partitions. Steel forms which may be rented are usually used for the columns, and steel forms may be used for the slabs. It is evident that the formwork for the slabs is very simple.

**Ribbed Slabs.** — In reinforced-concrete beams and slabs the concrete between the neutral axis and the tension face is not contributing to the flexural strength but is effective in resisting a part of the shearing stresses as explained in Article 42. The shearing stresses in slabs are usually low, so this concrete is not necessary. In order to save concrete and reduce the weight of the slab a large part of the concrete on the lower side of the slab is eliminated, leaving only the ribs or joists as shown in Fig. 120*a*, the bottom of the corresponding solid slab being at the bottom of the ribs. These ribs are made wide enough to resist the shearing stresses and to carry the necessary tensile steel which is practically the same amount as required for the solid slab except for the saving in steel due to the reduction of the dead load. The remaining flange may extend down

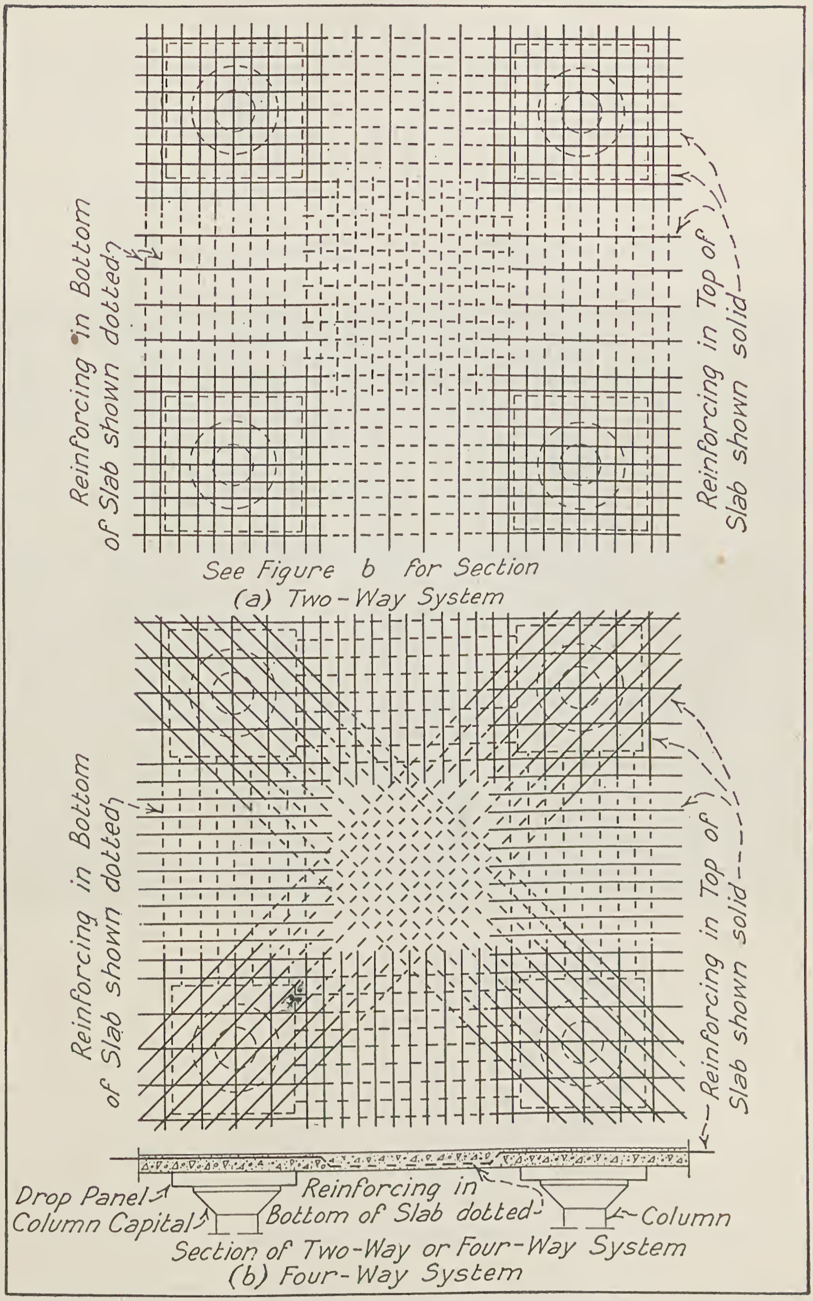



Fig. 119. Flat Slabs of Reinforced Concrete

*Courtesy of Portland Cement Association*

REINFORCED-CONCRETE FLAT-SLAB CONSTRUCTION

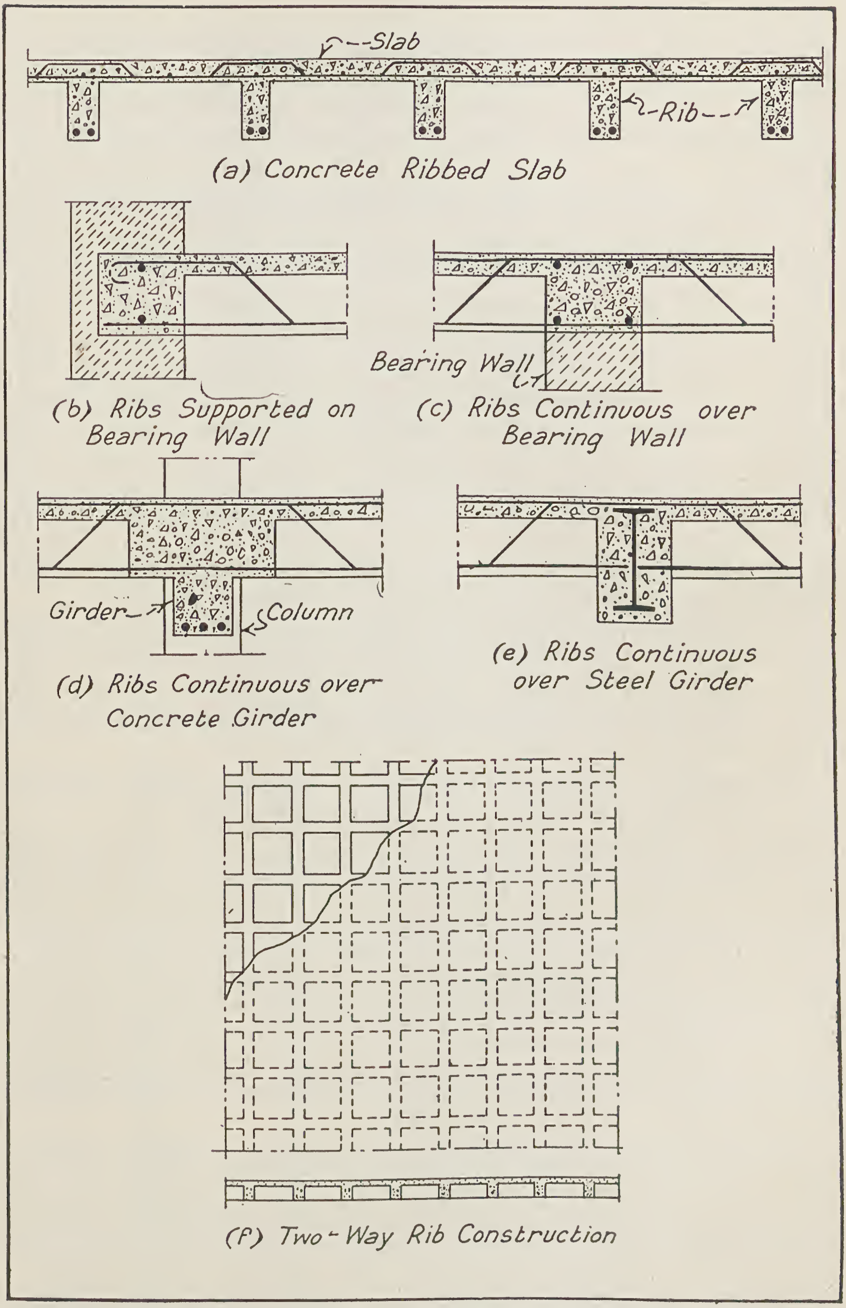



Fig. 120. Ribbed Slabs of Reinforced Concrete

to the neutral axis but usually it does not. This results in a reduction in the compressive resistance but this is small because the concrete near the neutral axis carries very little stress. This may be seen by consulting Fig. 54*e*. The solid slab would be reinforced with relatively small bars closely spaced, but in the ribbed slab two large bars are commonly used in each joist. This results in increased bond stresses but such stresses are not often a controlling factor. Some codes require solid bridging spaced not more than 8 ft. apart for all concrete joist floors. This bridging is commonly 4 in. wide and the full depth of the joists. It is reinforced with one rod near the top and one near the bottom. The function of such bridging is primarily to distribute heavy loads such as those due to partitions, safes, book cases, etc. over several joists. The minimum width of joists is 4 in. and the depth below the bottom of the slab is sometimes limited to three times the width. The slab between the ribs or joists varies from 2 to 4 in. in thickness and is reinforced with a wire mesh or with $\frac{1}{4}$-in. or $\frac{3}{8}$-in. bars about 12 in. apart running perpendicular to the joists and other small bars about 18 in. apart parallel with the joists. The bars are not bent up over the joists. Ribbed slabs are extensively used in fireproof buildings for spans from 10 to 35 ft.

The detail used where the end of a ribbed slab is supported by a bearing wall is shown in Fig. 120*b*. The details used for slabs continuous over bearing walls, concrete girders and steel girders are shown in Fig. 120*c* to *e*. The reinforcing in the slab is not shown in these figures but is the same as shown in Fig. 120*a*.

Occasionally it may be advantageous to support a slab on four sides and provide ribs in two directions as shown in Fig. 120*f*.

Ordinary wood forms would be so expensive for ribbed slabs that their cost would be prohibitive. For this reason various types of construction have been devised to take the place of such forms. The sides of the joists and the bottom of the slab are formed by hollow clay tile, hollow gypsum tile, or sheet-steel cores as shown in Figs. 121*a* to *c*. Wood forms are constructed for the bottoms of the joists as shown in Fig. 126*d*. These are usually made of 2-in. material and are enough wider than the joists to support the edges of the clay or gypsum tiles on the steel pans. The formwork is therefore very simple.

The clay tiles and the gypsum tiles provide a surface which serves as a plaster base for the ceiling formed by the underside of the slab. The ends of the end tiles may be closed by a thin slab made for that purpose, by using pieces of wire screen or in some other way, or they may be left open, in which case concrete will run a short distance into the cells.

The sheet-steel cores may be made of heavy material which will stand being removed after the concrete has set and being used several times.

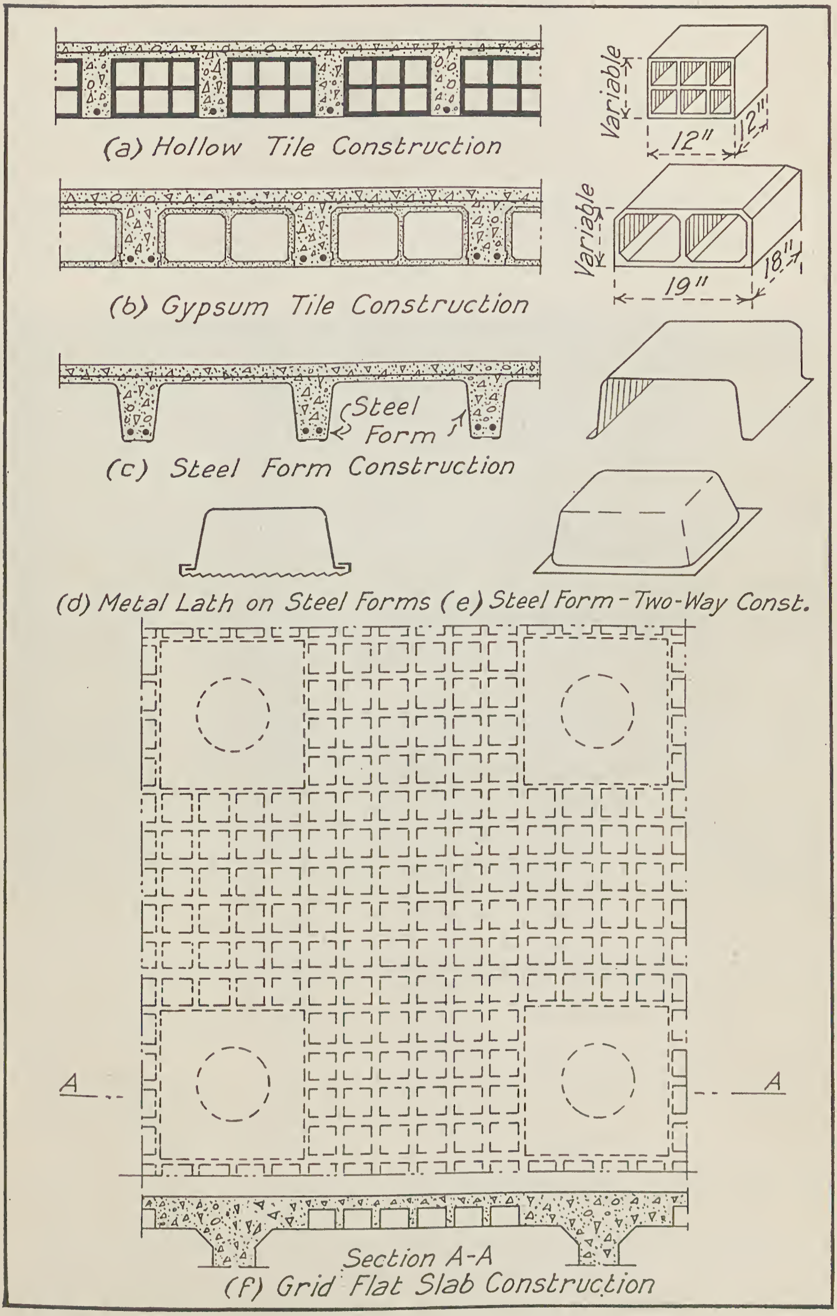
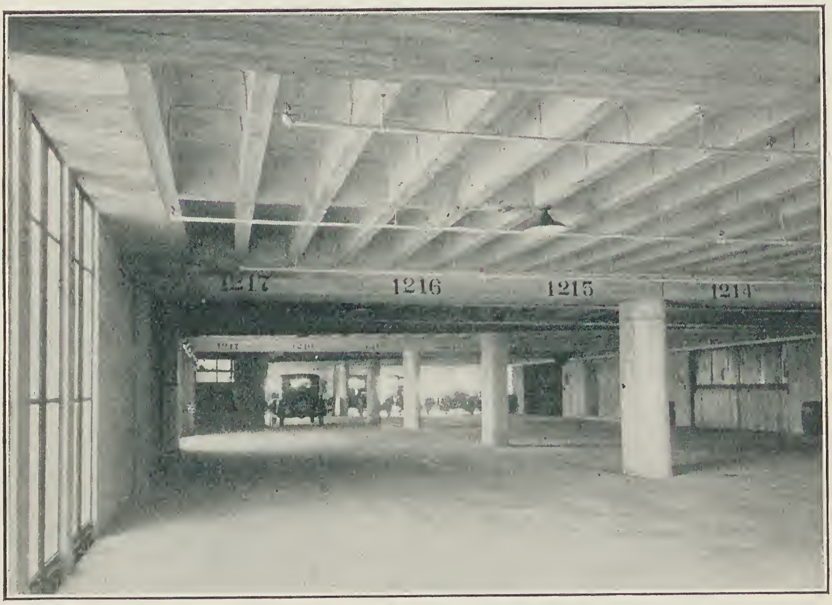



FIG. 121. Ribbed Slabs of Reinforced Concrete




*Courtesy of Portland Cement Association*

REINFORCED-CONCRETE RIBBED-SLAB CONSTRUCTION

They may also be made of thinner material designed to be left in place. If the removable forms are used, metal lath is fastened to the underside of the joists to serve as a base for plaster for the ceiling below. Various types of anchors are available for casting in the underside of the joists to receive the metal lath. If the sheet-steel cores are to be left in place, metal lath is laid over the forms before the cores are set. The metal lath is wired to the reinforcing bars in the joists. In one type of steel core, the lath is fastened to the core as shown in Fig. 121*d* before the core is placed. Sheet-metal closers or end caps are made for the ends of the end cores. It is sometimes necessary to widen the joists at the ends on account of excessive shearing stresses. This is accomplished by using tapered cores at the ends of the joists. The most common width of core is 20 in. which with a joist 4 in. wide gives a 24-in. joist spacing. The depths available vary from 6 in. to 14 in. by 2-in. increments. They are usually corrugated to increase their stiffness and are lapped one or one-half corrugations or more if necessary to provide the exact lengths required. The cores are supported on forms placed under the joists. No forms are necessary between the joists. Removable cores may be used several times but to stand moving they must be constructed of heavier metal than the cores which are left in place, the cost of removing must be considered and also the greater cost of placing the lath. The type most suitable for a given case can only be determined by studying all of the factors involved. Forms for this type of slab are shown in Fig. 126*d*.

An interior view showing a ribbed-slab floor constructed with removable sheet steel cores is given on page 344.

Special types of tile and sheet-steel cores are available for the two-way type of construction. A steel core for two-way construction is shown in Fig. 121*e*.

A form of flat-slab construction has been devised to make use of the ribbed slab in place of the flat slab. This is known as the *grid flat slab* and is illustrated in Fig. 121*f*. The reinforcing is not shown in this figure, but would be similar to that used in the two-way system shown in Fig. 119*a*.

The reinforcement of slabs should be protected against the action of fire by at least one inch of concrete.

## ARTICLE 44. REINFORCED-CONCRETE ARCHES AND RIGID FRAMES

The use of reinforced-concrete arches and rigid frames in building construction is increasing very rapidly. The most extensive use is in roof construction. A simple type of roof construction is illustrated in Fig. 122*a*. The roof consists of slabs running between beams or purlins which

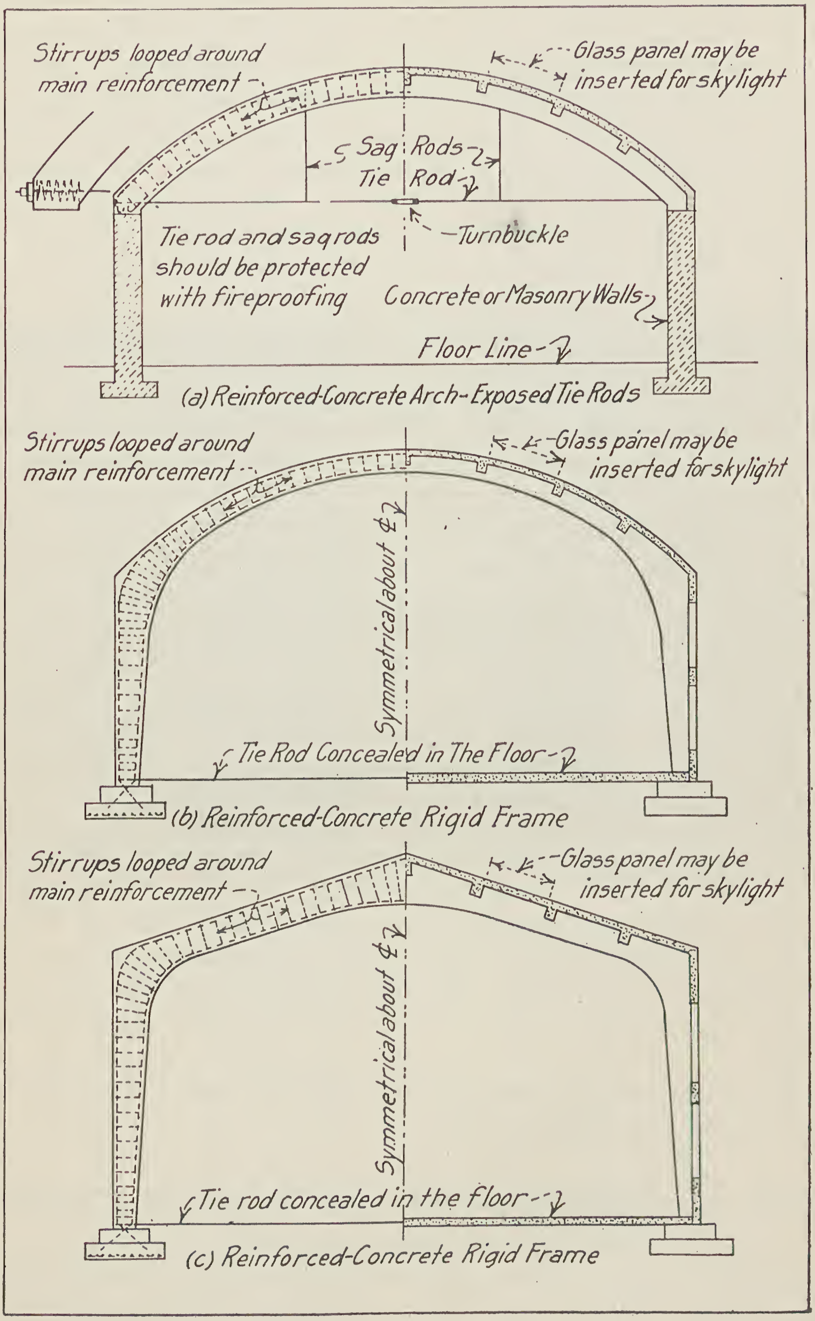



Fig. 122. Simple Reinforced-concrete Arches and Rigid Frames

are supported on reinforced-concrete arches spaced from 12 to 25 ft. or more apart. The horizontal reactions of the arches are taken by tie rods running from one side of the building to the other. These tie rods are supported at intervals by sag rods which hold them in a horizontal position. The ties and sag rods are protected by concrete fireproofing. The tie rod may be replaced by a reinforced-concrete tension member made up of several rods which are spliced by lapping a sufficient distance to develop their strength in bond. Arches of this type have been constructed with spans of 100 ft. and over.

Instead of using tie rods as shown in Fig. 122*a* the arch may be extended to the ground as shown in Fig. 122*b*. This permits the tie rods to be concealed in the floor. The bending stresses in the arch ring are greatly increased by using this type of arch but the structure is much more attractive than that with the exposed tie and the increased stresses are readily taken care of in design. Such a structure should probably be classed as a rigid frame rather than an arch. Another form of rigid frame which provides a sloping roof instead of a curved roof as in Fig. 122*b* is shown in Fig. 122*c*. Other types of reinforced-concrete rigid frames are shown in Fig. 59.

Arches and rigid frames offer great possibilities for future development and will doubtless have a pronounced effect on building design.

## ARTICLE 45. REINFORCED-CONCRETE FRAMING

In framing a reinforced-concrete building the forms are first constructed, the reinforcing steel is then placed, and finally the concrete is poured as described in Article 6. After the concrete has set the forms are removed. It is obviously impossible to pour an entire building in one operation, so construction joints can not be avoided. These should be so located and constructed as to impair the strength of the building as little as possible. The joints in slabs, beams, and girders should be vertical and at the center of the span where the shearing stresses are small. The columns should be poured to the underside of the floor girders for beam and girder construction and to the bottom of the column capital in flat-slab construction so that the shrinkage which occurs in the concrete of the columns may take place before the floor above is poured.

Forms are usually constructed of wood, but steel forms are quite extensively used especially for buildings of flat-slab construction. The reinforcing steel is held in position by wiring the bars together at their intersections. The bars for each beam, girder, and column are commonly wired together to form a frame which is set in position as a unit. Various

devices such as chairs and spacers have been devised to hold reinforcing steel in position.

Reinforced-concrete buildings may be of the bearing-wall type of construction or of skeleton construction. The bearing walls may be constructed of brick, stone, hollow tile, or plain concrete or they may be

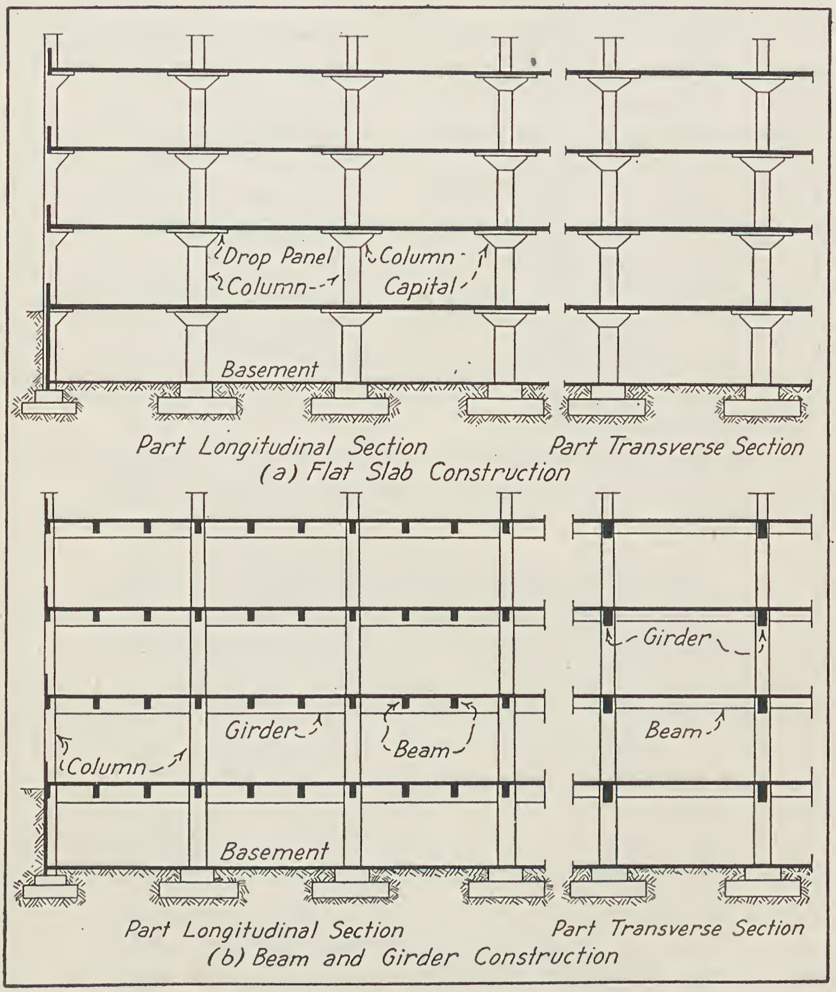
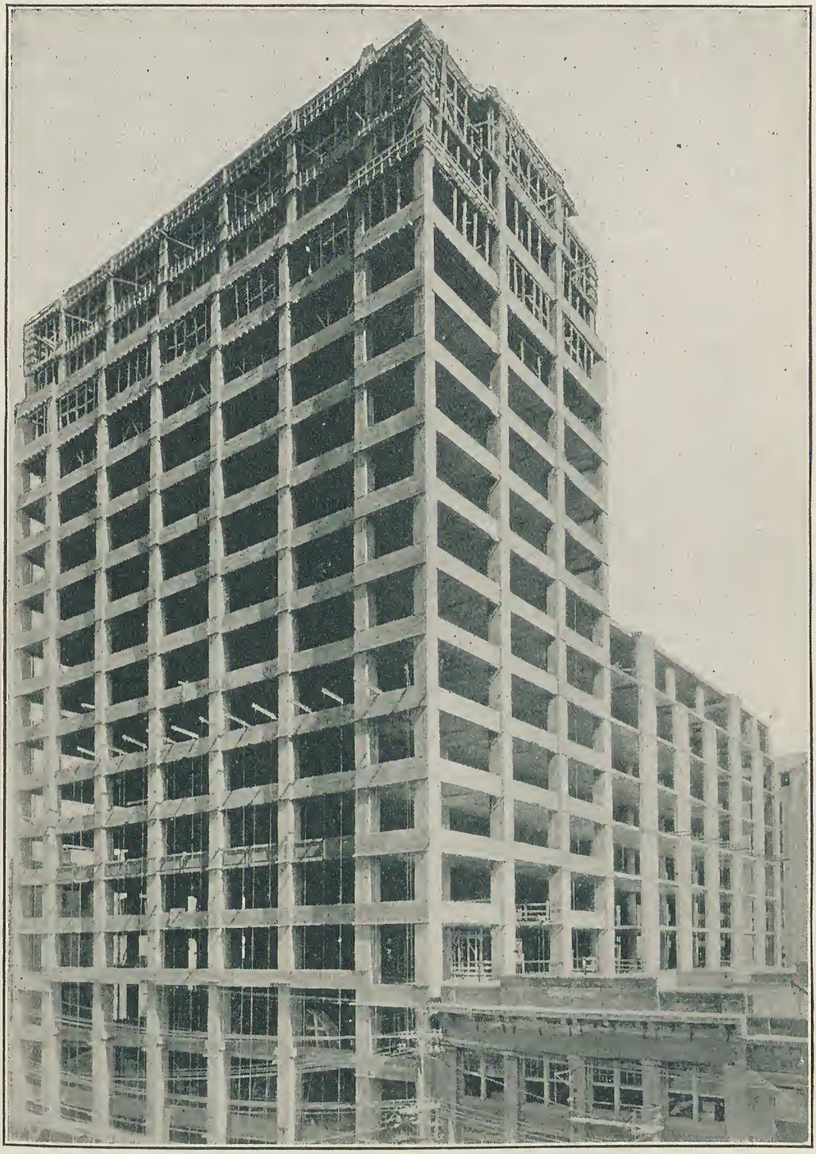



FIG. 123. Types of Reinforced-concrete Framing

constructed of reinforced concrete as shown in Fig. 52 and described in Article 22. Skeleton construction buildings may be of the beam and girder type as shown in Fig. 123*b* or of the flat-slab type as shown in Fig. 123*a*. A building with reinforced concrete bearing walls is shown on page 354 and a skeleton frame on page 349.



*Courtesy of Portland Cement Association*

Reinforced-concrete Skeleton Frame

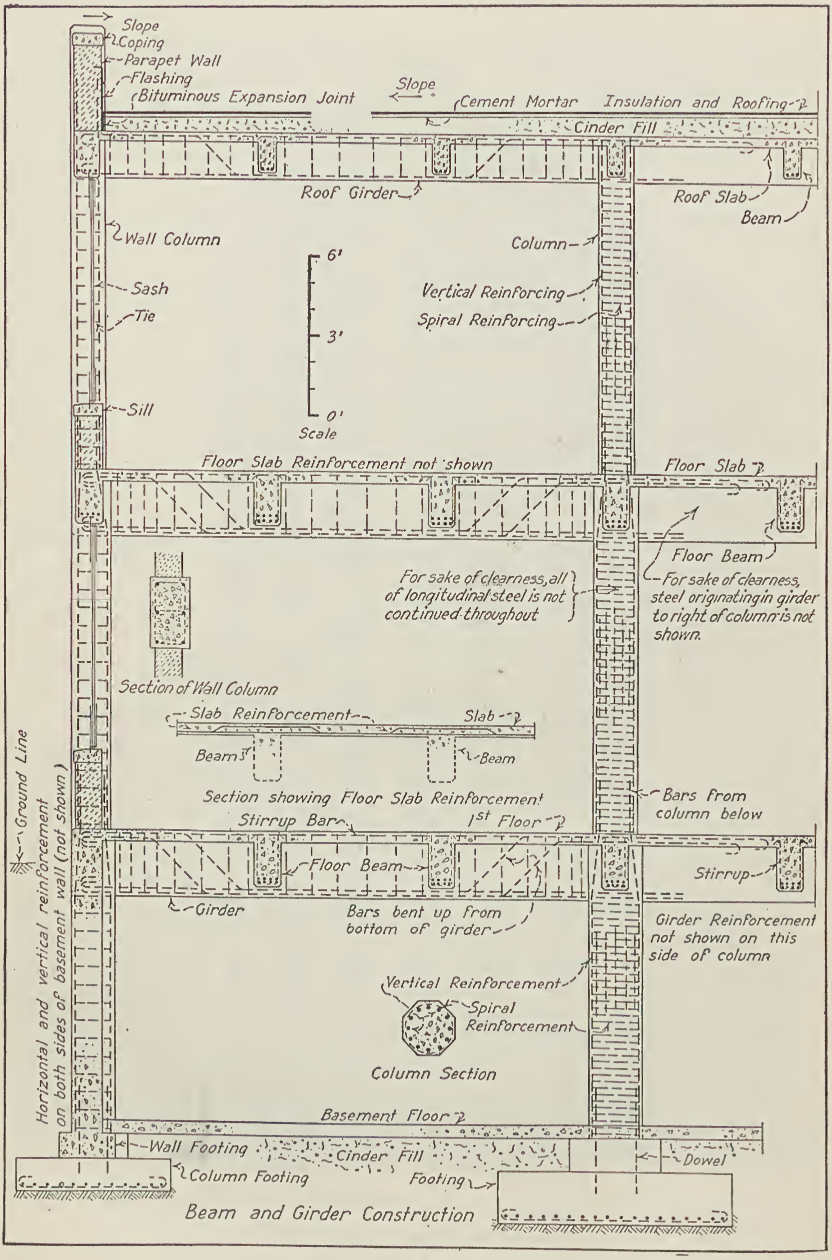



FIG. 124. Beam and Girder Construction

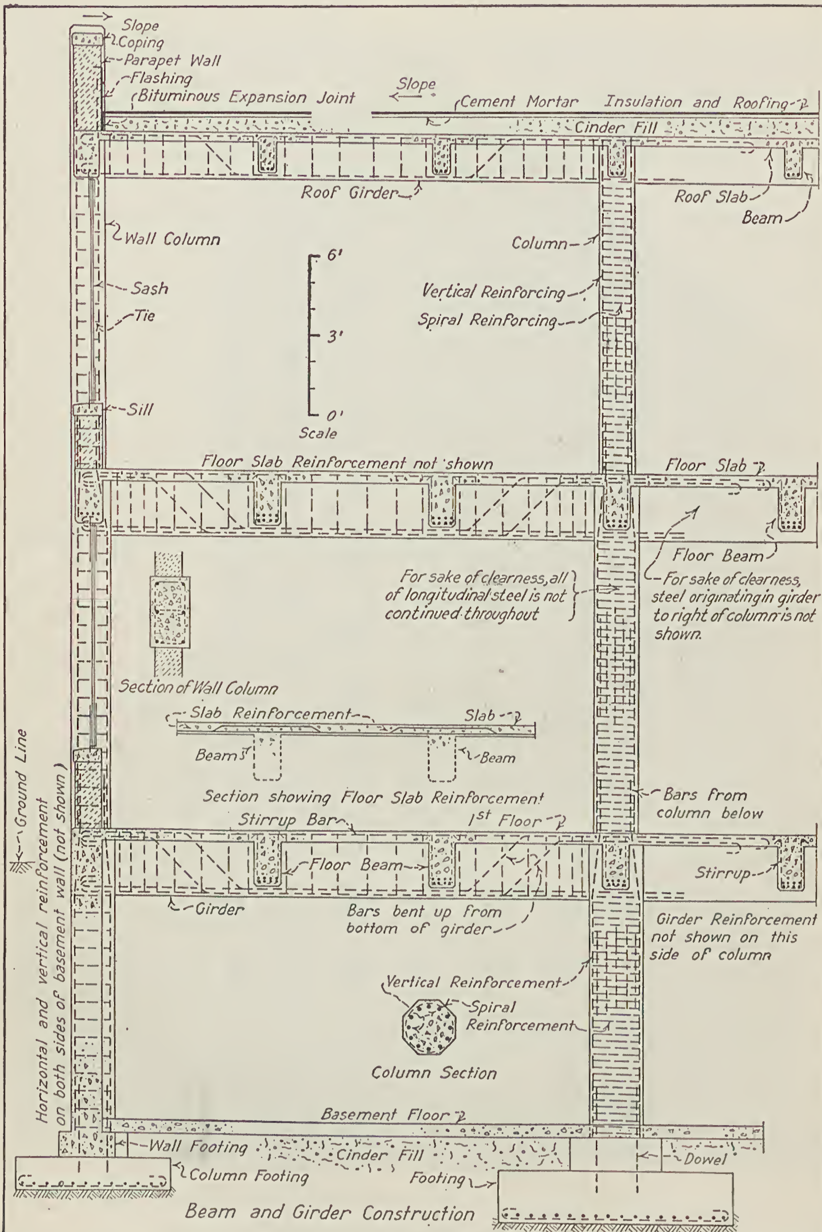



FIG. 124. Beam and Girder Construction

Typical details for a building of the beam and girder type are shown in Fig. 124. The features which should be noted in this figure are:

1. The reinforcing in the slab. Reinforcing is provided at the bottom of the slab near the center of the span and at the top where the slab crosses the beams. Some of the bottom steel continues through on the bottom.

2. The reinforcing in the beams is not shown but is similar to that in the girders and consists of horizontal bars in the bottom of the girder, and bars bent up from the bottom of the girder at the center to the top in the region near the supporting columns. The ends of the bars are hooked in most cases.

3. Vertical stirrups which are more closely spaced near the ends of the girder where the shearing stresses are high.

4. Spread footings are used. The reinforcing bars in the footings are hooked at the ends. Dowels extend from the footings into the columns. These dowels should be equal in size and in number to the longitudinal bars in the column as their function is to transfer the stress in the column bars to the footing. They must extend into the column and into the footing a sufficient distance so that their bond stress will not be excessive.

5. The longitudinal bars in the interior columns are arranged around the edge of the columns and are surrounded with closely-spaced spiral reinforcing. To avoid confusion all of the longitudinal bars are not shown in the elevation but they are shown in the section.

6. The longitudinal bars of the wall columns are held in position by lateral reinforcement in the form of ties which are not as closely spaced as the spirals of the interior columns.

7. The columns are spliced by running the longitudinal bars from one column upward into the column above. To take care of the smaller size of the upper columns the bars are bent inward in the part of the column occupied by the floor construction. They are again made vertical after the floor level is passed.

8. The slope of the roof is obtained by a cinder fill with a cement mortar topping to receive the built-up bituminous roofing. The cinder fill also serves as heat insulation. An expansion joint is provided between the filling and the parapet wall so that the topping can expand as it becomes heated. If this provision were not made the topping would either buckle or push the parapet wall out. Similar expansion joints should be provided at other points in the topping.

9. The panel walls consist of steel sash which occupy the entire width between columns and below which masonry walls are placed.

10. The parapet wall is capped with a coping the top of which slopes

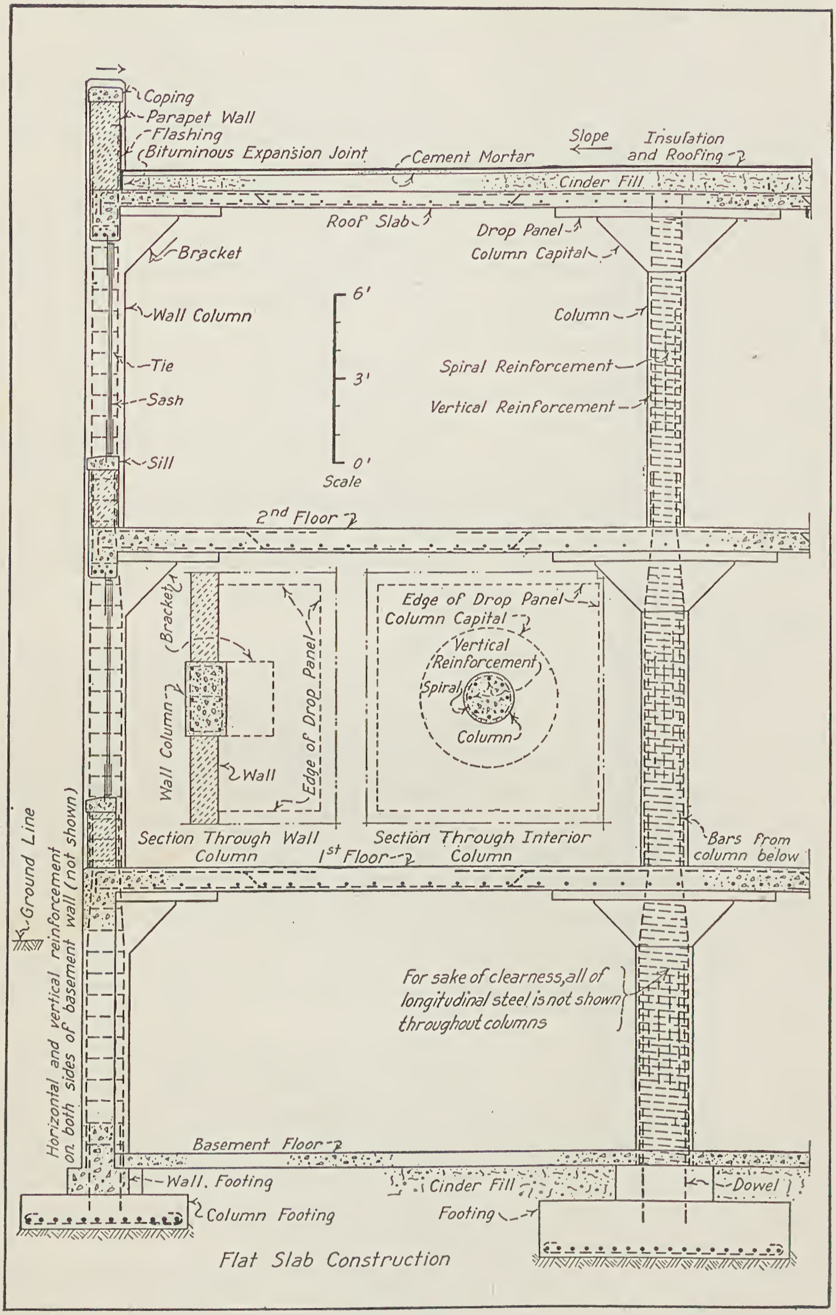



FIG. 125. Flat-slab Construction

towards the roof so that it will drain towards the roof and not over the face of the building.

For an interior view of a building of the beam and girder type see page 337.

Typical details of a building of the flat-slab type are shown in Fig. 125. The features which should be noted in this figure are:

1. The substitution of flat-slab construction for the beam and girder construction shown in the previous figure.

2. The drop panels and the column capitals of the interior columns.

3. The brackets and drop panels of the exterior columns.

4. The spiraled interior columns. For clearness only a part of the longitudinal bars are shown in the elevation but they are all shown in the section.

5. The tied wall columns. Since these columns are rectangular they are provided with intermediate ties.

Other features are the same as the corresponding features of the beam and girder type which have just been explained.

For an interior view of a building of the flat-slab type see page 340.

**Walls.** — Reinforced-concrete walls are discussed in Article 22 and illustrated in Figs. 50, 51, and 52, and on page 354.

**Wind Stresses.** — For buildings whose width is large in proportion to their height wind stresses are not an important factor but for tall slender buildings they must be given consideration. The various methods used in structural steel frames for resisting wind stresses are described in Article 39. The reinforced-concrete frame is a rigid structure in the members of which lateral forces produce flexural stresses and direct stresses. These stresses are provided for by increasing the sections and reinforcement as required and not by special details as used in steel construction.

**Earthquake Stresses.** — The discussion of earthquake resistance given in Article 39 applies to reinforced-concrete buildings as well as to buildings with frames of structural steel.

**Forms.** — The design and construction of forms are important phases of reinforced-concrete construction but will be given only brief consideration here. One type of form for a floor slab and beam is illustrated in in Fig. 126*a*. The sections of a form for a square column may be constructed separately as shown on the left of Fig. 126*b*. These are assembled as shown on the right. The separate parts are held together by cleats as shown. The forms are easily removed by taking off these cleats. A similar form for an octagonal column is shown in Fig. 126*c*. The forms for ribbed concrete slabs with hollow tile cores and with steel cores are shown in Fig. 126*d*.


*Russell and Alpaugh, Architects* *Courtesy of Portland Cement Association*

REINFORCED-CONCRETE MONOLITHIC WALL CONSTRUCTION

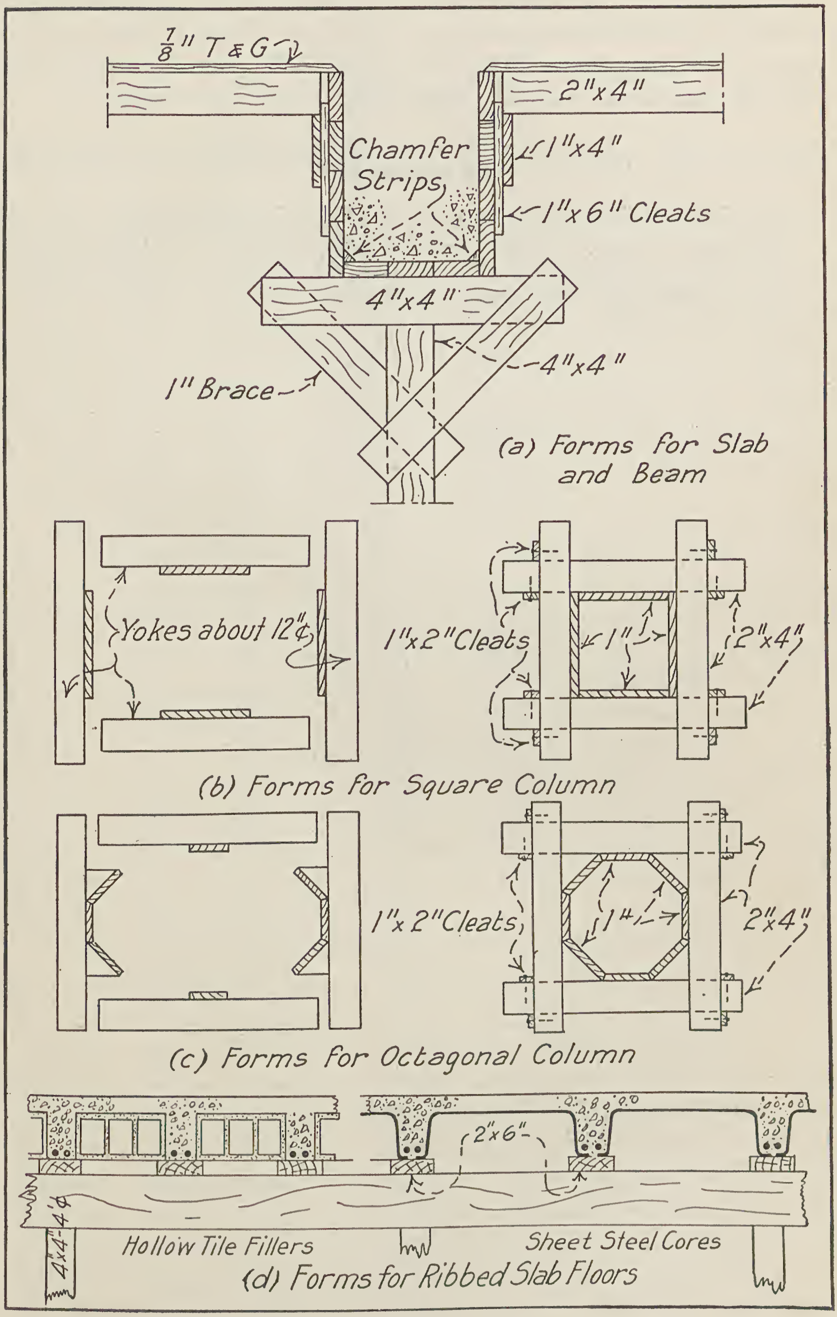



FIG. 126. Forms for Concrete

Steel forms are extensively used for buildings of flat-slab construction in which the dimensions are more or less standardized, so that the forms can be used many times without remaking. They are arranged so that they can be erected and taken down with a minimum of effort.

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# CHAPTER IX

# FLOOR CONSTRUCTION AND FLOOR SURFACES

## ARTICLE 46. TYPES OF FLOOR CONSTRUCTION

**Wood Floors on Wood Joists.** — The most common form of floor construction for non-fireproof buildings consists of wood joists supporting a 1-in. wood sub-floor, and a matched wood finished floor as described in Article 34, preferably with a layer of building paper or other material between the sub-floor and the finished floor as shown in Fig. 127*a* and Figs. 80 to 83 inclusive. Magnesite composition as described in Article 51 may be used in place of matched flooring, or the construction may be changed to receive tile, terrazzo, or other material.

The joists are usually 2 in. wide, and from 6 to 14 in. deep. For heavy loads the joists may be 3 or 4 in. wide. Wider joists are used in slow-burning construction, which is considered under another heading. Where wood lath is to be used the spacing must be such that a joist will come every 4 ft. to avoid waste, the lath being 4 ft. long. For this reason the usual spacings are 12 and 16 in., 24 in. being too great a space for good results with wood lath. Light metal lath requires a spacing not greater than 12 in., but greater spacing may be used with heavier lath. In some cases 1 × 2-in. furring strips, properly spaced for lath, and running at right angles to the joists, are nailed to the under side of the joists to receive the lath. In this case the spacing of the joists is independent of the lath. This construction enables fire to spread rapidly across the joists, so is objectionable.

An important function of the sub-floor is to provide a floor during the early stages of construction, the finished floor being laid after the plastering is done. A sub-floor makes the floor more substantial, more fire-resistant, more sound-proof, and warmer. When a sub-floor is used there is a tendency to nail the finished floor to the sub-floor rather than to the joists. This practice is objectionable because the finished floor does not remain in place as well when nailed to the sub-floor and tends to squeak. There is also a tendency to lay the finished floor parallel with the joists, which is very objectionable. The sub-floor should be laid diagonally, or if strips are placed over the joists, the finished floor and sub-floor may both be laid at right angles to the joists, the strips overcoming the uneven places in the sub-floor. The sub-floor may be of ordinary sheathing, matched boards, ship-lap, or a special product

consisting of wood strips on an asphaltic felt as described under roof sheathing. Often the sub-floor is omitted entirely to decrease the cost, in which case the finished floor would probably have to be laid before

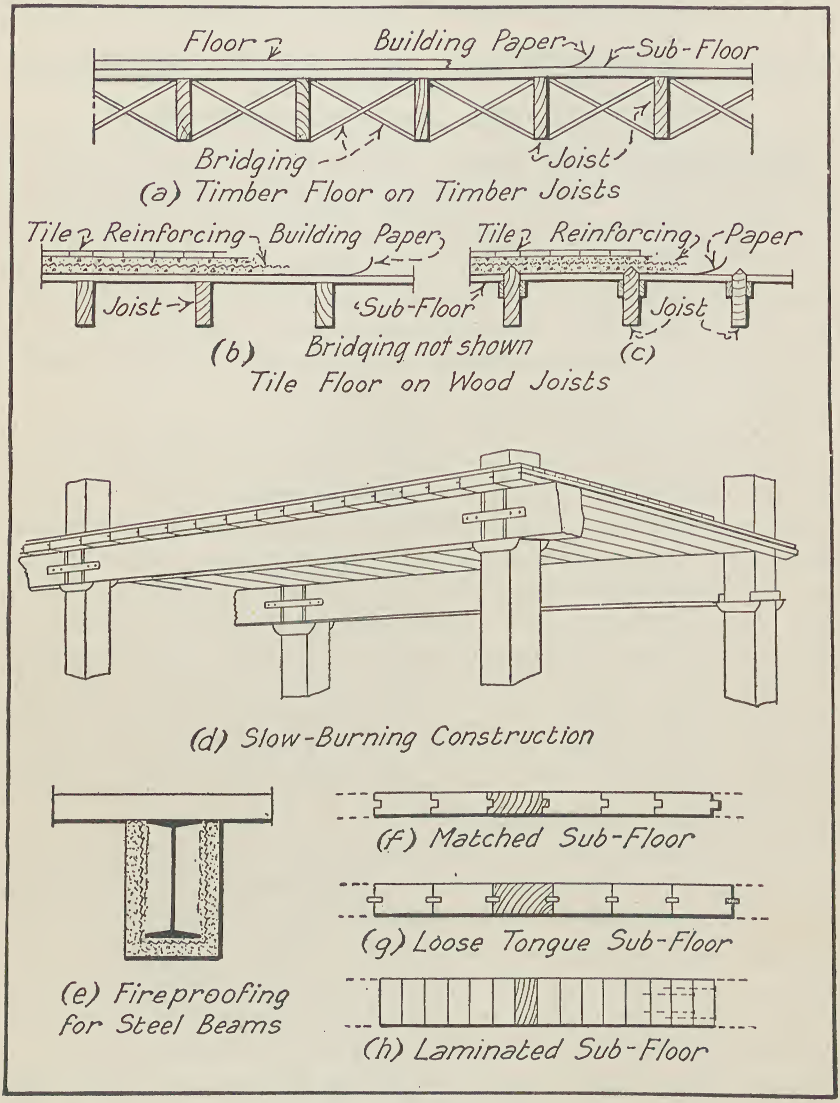


FIG. 127. Timber Floors

plastering, during which operation it must be protected from dirt and water.

The layer between the sub-floor and the finished floor may be omitted

entirely or may consist of building paper, asphaltic felt, asbestos paper, plaster board, or of concrete $1\frac{1}{2}$ to 2 in. thick reinforced with a light wire mesh, or expanded metal. Some form of incombustible layer should always be used; and if the cost will permit, the increase in fire-resistance and sound deadening properties due to a layer of heavy asbestos paper or plaster board will warrant the additional expenditure.

The joists are held in a vertical position by cross bridging as shown in Fig. 127*a*, one row being used where the span of the joists is over about 8 ft., and two rows where over 16 ft. Cross bridging also serves to distribute concentrated loads over several joists.

Where a tile floor is to be placed on wood-joist construction the floor must be designed to carry a reinforced-concrete slab, as shown in Fig. 127*b*, to act as a base for the tile. The construction shown in Fig. 127*c* is also used, but is more likely to produce cracks than the construction in Fig. 127*b*.

This type of floor construction is used in residences and other buildings of ordinary construction, and may be used in buildings with steel frames. It is inexpensive, light, and may be made sufficiently strong for heavy loads, but is very combustible. If protected on the under side by plaster on metal lath its resistance to fire is greatly increased.

**Heavy Timber Sub-floor on Timber or Steel Beams.** — Timber subfloors varying in thickness from 3 in. to 10 in., depending upon the loading and span, may be supported directly by girders running between columns as shown in Fig. 127*d* and Figs. 84 and 85, or by beams which are supported by the girders as shown in Fig. 86 and described in Article 34. In the first arrangement the lateral spacing of columns must not be over 10 or 12 ft. on account of the heavy sub-floors required for longer spans. In the second arrangement the beams are spaced 4 ft. or more apart, and the column spacing is not restricted by the strength of the sub-floor.

To secure resistance to fire, timber beams and girders are made at least 6 in. wide, and at least 10 in. deep, even though the loads may not require beams of this size. If steel beams are used they should be protected against fire as shown in Fig. 127*e*.

Heavy timber sub-floors may be of three types, i.e., *matched* as shown in Fig. 127*f*; *loose tongue* as shown in Fig. 127*g* or *laminated* as shown in Fig. 127*h*. The matched floor may be used for thicknesses of 3 or 4 in., but for greater thicknesses the waste in matching becomes so great that the hardwood loose tongue may be more economical. This loose tongue is also called a *slip tongue* or *spline*.

Floors 4 in. and over in thickness may be constructed by laying 2-in. lumber on edge, and securing the adjacent pieces together with spikes

spaced about 18 in., 2 × 4's being used for a 4-in. floor, 2 × 6's for a 6-in. floor, etc. This type of floor is known as a "laminated" floor. A laminated floor is easier to lay than a heavy loose-tongue floor for the pieces being smaller are more easily handled, and drawn into position, but more feet board measure are required, as 2-in. material is really $1\frac{5}{8}$ to $1\frac{3}{4}$ in. thick. The cost of the loose tongue is saved in the laminated floor.

When the details are properly worked out this type of construction, using timber in large masses, is called slow-burning construction on account of the slow progress which fire makes in burning the heavy timber. It is also called mill construction because of its extensive use in textile mills. See Article 34.

**Concrete Slabs on Light Steel Joists.** — Various forms of light steel joists are described in Article 36 and illustrated in Fig. 91. A floor consisting of a thin concrete slab supported on strip joists or steel lumber is illustrated in Fig. 128. The spacing of strip joists, plate girder joists and trussed joists varies from 18 to 30 in. The joists are bridged at

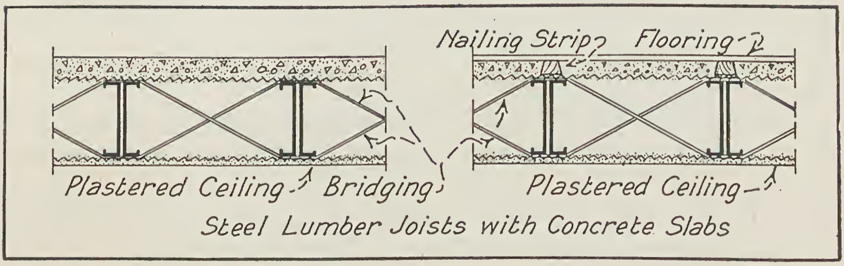


FIG. 128. Pressed Steel Joists with Concrete Floor Slabs

intervals of not over 6 ft. with galvanized wire as shown in the figure. The slab has a minimum thickness of 2 in. and is reinforced with ribbed steel lath. No forms are used, the mesh of the lath used being sufficiently small to hold the concrete, and the ribs being sufficiently rigid to prevent excessive sagging. The concrete grips the rough mesh of the lath to develop the required bond strength. If a wood wearing surface is to be used, wood screeds or nailing strips are fastened to the joists as shown in the figure. A metal lath and plaster ceiling is applied to the under side of the joists as fireproofing and to improve the appearance.

**Other Types.** — Reinforced-concrete slabs supported by steel beams are described in Article 43 and illustrated in Fig. 118.

Reinforced-concrete slabs supported by reinforced-concrete beams are described in Article 43 and illustrated in Fig. 118.

Reinforced-concrete flat-slab construction is described in Article 43 and illustrated in Fig. 119.

Reinforced-concrete ribbed slabs supported by steel or reinforced-concrete beams are described in Article 43 and illustrated in Fig. 120.

Hollow clay-tile arches supported by steel beams are described in Article 20 and illustrated in Fig. 48.

Brick arches supported by steel beams are described in Article 18 and illustrated in Fig. 34*a*.

## ARTICLE 47. GROUND FLOOR CONSTRUCTION

The wearing surfaces for floors are discussed in Articles 48 to 54. Any of these wearing surfaces may be used on floors resting on the ground if the sub-floor and base are properly constructed. The various types of bases for ground floors will be discussed in this article.

Unless the ground on which the floor is to be placed is free from water and certain to remain so, an effective drainage system should be installed under the floor. This system may consist of lines of drain tile or sewer tile with open joints laid at intervals under the floor, and connected to a sewer or drain to conduct the water away. A layer of gravel, cinders or crushed rock, from 6 to 8 in. thick is placed under the base to permit the water to reach the drains. If the ground is not likely to contain water the drainage system is unnecessary, and the porous base of crushed rock, gravel, or cinders will tend to keep the dampness from the ground from reaching the base. A layer of asphaltic felt laid on top of the porous layer will assist in making a dry floor if a concrete base is used. See Articles 15 and 16.

The bases used to support the wearing surface of ground floors are usually of two general types, portland cement concrete, or bituminous concrete. A portland cement concrete base is from 4 in. to 6 in. thick. If the wearing surface is to be of concrete, the floor is sometimes divided into 6- or 8-ft. blocks to prevent cracks due to changes of temperature or shrinkage. If the wearing surface is to be of brick, a cushion of sand, cement mortar, or bituminous mastic is used between the base and the brick. Clay tile wearing surfaces are placed on a layer of cement mortar. Such surfaces as linoleum or cork carpet are cemented directly to the concrete base, the surface of which must be finished as smoothly as though it were going to be used for a wearing surface. If there is any possibility of the floor being damp it should be waterproofed if such surfaces as linoleum or cork carpet are to be used.

If a wood-block wearing surface is to be placed on a concrete base a thin, damp-proof layer of sand mixed hot with pitch, tar or asphalt must be placed on the concrete. The wood blocks are bedded on this layer before it has hardened. If a wood matched-flooring wearing surface is

to be used a sub-floor consisting of a layer of 3-in. planks side-nailed together is placed on the damp-proof layer before it has hardened. The matched flooring is placed on the wood sub-floor, the flooring being placed at right angles to the plank. See Fig. 129*a*. A more substantial sub-floor may be secured by replacing the layer of 3-in. plank with two layers of 2-in. plank, the top layer being laid diagonally and the wearing surface at right angles to the bottom layer. See Fig. 129*b*. The sub-floors described above may be made of material either thicker or thinner than

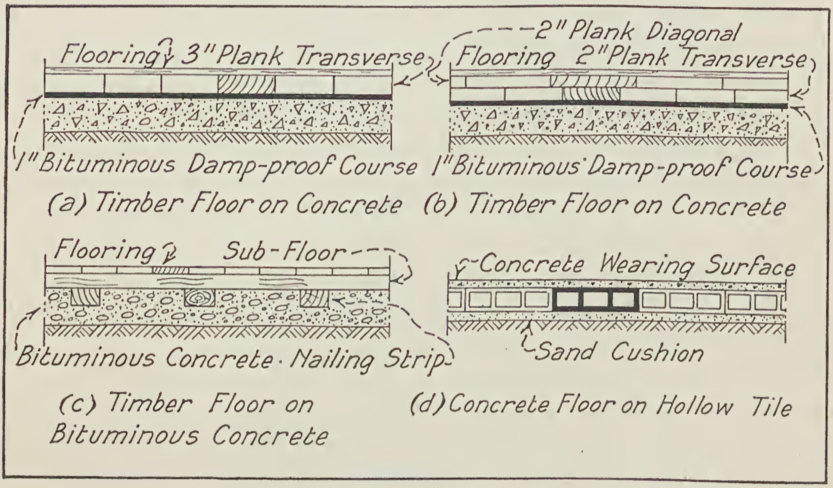


Fig. 129. Ground Floor Construction

that mentioned above if the conditions warrant. In all cases it is desirable to give the wood in the sub-floor a preservative treatment. Wood nailing strips or sleepers should never be embedded in a concrete base for a ground floor, for they will soon decay. A base of bituminous concrete may be used in place of the portland cement concrete for wearing surface of wood or brick. The bituminous concrete corresponds to portland cement concrete with tar, pitch, or asphalt for a cementing material instead of portland cement. The materials are mixed and placed hot. Wood nailing strips or sleepers may be embedded in bituminous concrete with a wood sub-floor bedded on a damp-proof layer nailed to these strips as shown in Fig. 129*c*.

The base of a ground floor may consist of a layer of hollow clay-tile blocks laid on a sand cushion resting on firmly compacted earth or gravel as shown in Fig. 129*d*. These tile should be dense and hard-burned. A concrete wearing surface an inch or more in thickness would be used with this type of base. The air space in the tile insures a dry floor. If water is present a drainage system must be installed as with other types.

## ARTICLE 48. SELECTING TYPE OF FLOOR CONSTRUCTION

In selecting a type of floor construction to use in a building the following factors should be taken into consideration:

1. General type of construction used in the building.
2. Plan of building.
3. Floor loads.
4. Resistance to fire.
5. Ceiling; flat or exposed beams.
6. Direct cost.
7. Indirect cost; effect of weight and thickness.
8. Floor covering.
9. Position of floor; ground floor or above ground.
10. Use of building.

These factors overlap each other in many cases, and their relative importance varies with different classes of buildings.

**General Type of Construction.** — If the beams, girders, and columns are of timber the floor construction will usually be of timber; if a steel frame is used the floor construction may be timber, plain or ribbed concrete slabs, or hollow tile or concrete arches; whereas if the supporting frame is concrete the floor construction may be plain or ribbed concrete slabs or flat-slab construction. If bearing walls are used throughout flat-slab construction would of course be impossible. However, this type of construction can be used with exterior bearing walls.

**Plan of Building.** — If the building is divided into panels which are very nearly square, flat-slab construction may prove to be desirable, or plain two-way plain or ribbed concrete slab with beams on the four sides of each panel may be seriously considered. If the spans are short the plain slab might be used, whereas for long spans the ribbed slabs will be found to be more satisfactory. If the building is to be divided into rooms flat-slab construction is not as satisfactory as it is for undivided areas on account of the interference of the column capitals with the partitions. Concrete ribbed slabs are particularly suitable for long spans. Flat-slab construction is not suitable for irregular plans.

**Floor Loads.** — Light steel joists may be used for light loads, such as those found in apartment houses, office buildings, and schools, but are not suitable for heavy loads. For very heavy loads brick arches might be used, but their use is rare. Flat-slab construction has advantages for heavy loads which it does not possess for light loads.

**Resistance to Fire.** — When a building must be cheaply constructed and resistance to fire is not a decisive factor, ordinary wood-joist con-

struction with wood sub-floor may be used. These conditions prevail in residence construction more than in any other class of building.

In warehouses and many types of industrial buildings slow-burning construction may offer sufficient resistance to fire and provide a building at a lower cost than that of a fireproof building.

In the congested downtown districts of many cities building ordinances require fireproof construction, so that wood-joist construction and slow-burning construction could not be used. Floors constructed of steel joists, although incombustible, are not sufficiently fire-resistant to be accepted in all cases. Flat-slab construction and plain concrete slabs withstand the action of fire better than ribbed slabs, but the latter are very satisfactory. In severe fires the lower shell of hollow tile used in ribbed slabs has been known to split off, and in some cases sheet-steel forms left in place have been expanded by heat and have forced the plastered ceiling off. In these cases the structural value of the floors is not destroyed. Hollow tile, brick, and concrete arches have satisfactory fire-resisting qualities when properly constructed.

The cost of fire insurance is an important factor entering into the choice of floor construction, the rates depending upon the fire-resistance of the construction as well as the nature of the contents, the location, and many other factors. The rate is lowered in many classes of buildings by the installation of automatic sprinkler systems which come into action in any part of a building when the temperature in that part is raised by fire.

**Ceiling.** — Ordinary wood-joist construction, flat-slab construction, ribbed concrete slabs, and flat tile arches provide flat ceilings, but plain concrete slabs supported by beams and girders, and segmental arches of brick, hollow tile, or concrete require suspended ceilings if flat ceilings are desired. In addition to their better appearance, flat ceilings offer advantages in fire protection by sprinkler systems and in lighting.

**Direct Cost.** — The direct cost of a floor will be assumed to include the cost of the floor slab, arches, etc., plus the cost of the supporting beams and girders ready to receive any base course required by a wearing surface, but not including the cost of such base, the wearing surface, the plastered ceiling or the supporting columns and foundations.

On this basis the various types, not including ground floors, may be arranged in the following order according to the direct cost, the least expensive being given first:

1. Light wood-joist construction.
2. Heavy timber construction.
3. Metal lumber and reinforced-concrete slab.
4. Reinforced-concrete slab and beams.

5. Reinforced-concrete ribbed slabs with steel forms.
6. Reinforced-concrete ribbed slabs with clay tile or gypsum tile.
7. Hollow clay tile arches and steel beams.

The exact order will be affected by local conditions and changing prices of materials and labor, but the list will give a fair idea of relative costs. Where a steel frame is used the supporting beams would naturally be of steel, and with a concrete frame they would be of concrete.

For floors carrying fairly heavy loads and with square or nearly square panels of uniform size, flat-slab construction would probably be placed third in the list.

Panels which are square or nearly square may make possible the use of two-way plain or ribbed concrete slabs, which cost less than the corresponding one-way slabs.

The actual cost of each type is affected by the span and the load to be carried as well as by the cost of the materials and labor. In one case on which comparative figures were determined the direct cost of light joist construction was 20 cents per square foot, and the cost of ribbed slabs with clay-tile fillers was 72 cents, not including supporting girders.

**Indirect Cost.** — The indirect cost of a floor will be assumed to include the cost of the base for the wearing surface, the cost of the plastered ceiling, the effect of the weight of the floor on the cost of the columns and foundations, and the effect of the total thickness on the height of the building and therefore on the cost.

If wood flooring is to be used for the wearing surface, light wood-joist and heavy timber construction have a distinct advantage in cost over other forms of floor construction where nailing strips with concrete fill between have to be provided at a cost of approximately 15 cents a square foot. The closely-spaced light steel joists may be covered with nailing concrete and thereby avoid most of this cost, or nailing strips may be placed directly over the joists with a light concrete slab between nailing strips. See Fig. 128.



If the wearing surface is to be linoleum, cork, concrete, composition, light asphalt mastic, carpet, rubber, tile, etc., any of the forms of floor construction which provide a concrete top surface are suitable but the additional cost of providing a finished surface must be considered. With wood-joist or heavy timber construction a concrete surface would add greatly to the cost; asphalt mastic, and linoleum, etc., require a matched floor; but composition can be laid on the sub-floor.

Clay tile, marble, slate, and terrazzo require a concrete foundation, so the various forms of floor construction which provide a concrete top surface are suitable for the installation of these materials without

further expenditure, but wood sub-floors require a 2-in. or 3-in. slab which increases the cost considerably. See Fig. 127*b*.

Plastered ceilings are provided by applying two coats of plaster directly to the under side of flat tile arches, ribbed slabs with clay or gypsum tile fillers, flat slabs, or plain slabs supported by concrete or fireproofed steel beams. The ribbed slabs and the flat slabs provide a flat ceiling, but the slabs supported by beams necessitate breaks in the ceiling, and the cost of plastering is greater on account of the increased area and the additional labor required in finishing around the edges of the beams. Wood joists, heavy timber construction, metal joists, and ribbed slabs with steel forms require lath and preferably three coats of plaster on the under side to provide a plastered ceiling. The ceiling supported by wood joists, ribbed slabs with steel forms, and metal joists will be flat; whereas the ceiling supported by heavy timber construction will probably follow around the beams. The cost of the lath and the additional cost of plaster should be considered in selecting the floor construction.

It is evident that the heavier slabs will require a more costly supporting structure. Wood and metal joists have the advantage in this respect, and ribbed slabs with clay tile fillers as well as concrete slabs supported by beams are at a disadvantage.

The minimum height of building for given clear ceiling heights is obtained with flat-slab construction. Ribbed slabs and metal joists are also satisfactory in this respect if the girders running one way come over partitions, as they usually do. Concrete slabs supported on beams and girders take up the most room. Any increase in height means an increase in the cost of walls, columns, elevators, stairways, and many items which may be small individually, but which may reach a total which is worth considering.

Where the cost is an important factor in the selection of the floor construction, comparative estimates of the various types will usually be made.

**Floor Coverings.** — It is possible to place any floor covering on any form of floor construction, but the cost of preparing the supporting floor to receive the wearing surface must be considered, as has just been explained.

**Use of Building.** — The use which is to be made of a building enters into the choice of the general type of construction as explained in Article 2.

The use is a determining factor in the selection of the particular type of floor construction only to the extent that the desirability of flat ceilings, the need for durable and fireproof construction, the magnitude and character of the floor loads, and such factors are influenced by the use.

## ARTICLE 49. MATCHED WOOD FLOORING AND WOOD BLOCKS

**Matched Wood Floorings.** — Finished floors of wood may be used over all types of floor construction. Where wood joists are used the wood is nailed to these joists, but with concrete slabs, terra cotta arches, and many other types of supporting floors, it is necessary to embed nailing strips in a layer of concrete. Such strips may be beveled as shown in Fig. 130*a* so that they will be held in place by the surrounding concrete; they may be held in place by driving nails at intervals in the sides of the strips before the concrete is poured; expansion bolts or screws may be

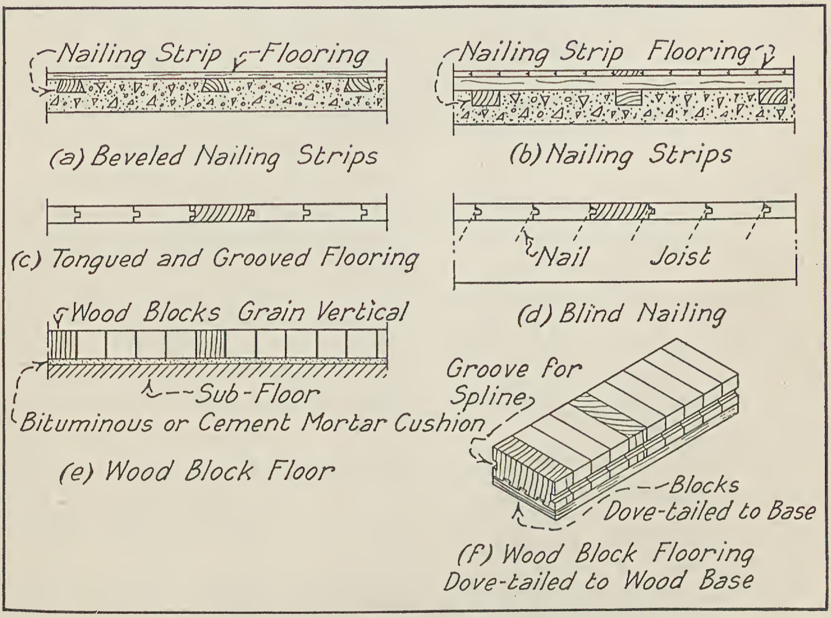


FIG. 130. Types of Wood Floor Surfaces

used to anchor the strips; or the strips may be placed on other strips at right angles to them to which they are nailed, the whole being embedded in concrete as shown in Fig. 130*b*. Preparations known as "nailing concretes" are on the market and may be used instead of nailing strips. These are concretes of special composition which will allow nails to penetrate, and which make possible the nailing of a wood finished floor directly to the nailing concrete. Such concretes are usually applied in a layer 2 in. thick with the top surface struck very accurately to receive the finished floors.

Wood flooring, with minor exceptions, is tongued and grooved or matched as shown in Fig. 130*c*. The sides only are matched in most soft

woods, such as fir and pine, but the hardwoods are end-matched also, so a joint is not necessarily directly over a joist or nailing strip. The most common thickness of flooring is $\frac{13}{16}$ in. and the most common widths are 3 in. and 4 in. for the soft woods, and 3 in. for the hardwoods. The exposed face on 3-in. flooring is $2\frac{1}{4}$ in. and on 4-in. flooring is $3\frac{1}{4}$ in. Hardwood floors are often only $\frac{3}{8}$ in. thick in residence and office buildings; and in industrial buildings, gymnasiums, and many other classes of buildings, maple floors $1\frac{1}{16}$ in. thick are used on account of the severe usage. Matched floors are fastened to joists or nailing strips by blind nailing as shown in Fig. 130*d*.

Wood flooring is divided into two classes according to the direction of the grain. When the grain of the wood makes an angle less than 45 degrees with the vertical the wood is classed as quarter-sawed, edge-grained, or vertical-grained; and when the angle is greater than 45 degrees the wood is classed as plain-sawed, flat-sawed, or flat-grained. See Article 10.

Many kinds of wood flooring are on the market including oak, maple, birch, beech, white or soft pine, yellow or hard pine, spruce, fir, hemlock, redwood, cedar cypress, tamarack, walnut, and teakwood. The cheapest flooring on the market is probably flat-grained fir, which is soft and splinters very badly. It should never be used except where a floor gets very little use. Quarter-sawed fir is much more durable than flat-sawed, but is less durable than quarter-sawed yellow pine, or the hardwoods.

White pine, or soft pine, as it is sometimes called, is not as durable as fir, but quarter-sawed soft pine may be satisfactory if it is not subjected to severe use. It will take any desired finish and may make an attractive floor.

Yellow pine, or hard pine as it is sometimes called, is more durable than fir. Quarter-sawed yellow pine is quite extensively used in residences, office buildings, and school houses, and gives satisfactory service, but is not as durable as the hardwoods. It is more expensive than fir and cheaper than the hardwoods, such as maple or oak.

Maple is a hard, close-grained wood, which will stand rough usage better than any other wood used for flooring. It is extensively used in industrial buildings, warehouses, gymnasiums, stage floors, and dance halls for this reason. Maple is also used in apartment houses, office buildings, hotels, and residences, and is quite satisfactory for kitchen and bathroom floors. Beech and birch are similar to maple, but are not as durable and are not used as much. They are more pleasing in color than maple and are somewhat cheaper. Maple, beech, and birch flooring are finished in three grades, depending upon the quality, i.e., Clear, No. 1,

and Factory. The best grade is somewhat cheaper than the best grades of oak and pine. The terms, quarter-sawed and flat-sawed, do not apply to maple, beech, and birch.

There are two general classes of oak: i.e., red and white. Each may be obtained either flat-sawed or quarter-sawed. All classes of oak are durable and attractive, the most durable probably being quarter-sawed white oak, and the least durable flat-sawed red oak. Oak flooring is graded according to quality into five grades: i.e., Clear, Sap Clear, Select, No. 1 Common, No. 2 Common. Quarter-sawed oak flooring is furnished in the first three grades only, and plain-sawed in the last four only. Oak floors are used in residences, office buildings, apartment houses, and similar buildings. The lower grades, No. 1 and No. 2 Common, are used only in a cheap class of buildings.

Matched wood floors should be used outdoors only when protected by a roof and kept well painted.

**Parquet Flooring.** — Parquet or parquetry flooring consists of flooring of relatively small lengths cut to form patterns or mosaics. Usually square-edge flooring $\frac{5}{16}$ in. thick and 2 in. or less in width is used but wider and thicker material square-edged or matched is used. The more complicated designs are furnished glued to a backing for convenience in laying. The thin square-edge pieces are fastened to the wood sub-floor with brads driven through the face and with heads set in about $\frac{1}{16}$ in. with a nail set. The floor is then made smooth with a plane or scraper. After it has been filled and given its primary coat of varnish, the holes left by the nail heads are filled with putty and the final coats of varnish and wax are applied.

**Wood Blocks.** — Wood blocks of yellow pine or redwood are used for the wearing surface of floors in some cases when the usage is very severe. These floors are laid on any of the sub-floors described in the previous articles. The grain of the wood is always vertical, and the blocks may be obtained with or without preservative treatment. The thickness varies from 2 in. to 4 in. depending upon the severity of the service. The joints between the blocks are filled with a bituminous filler and the blocks are set on a bituminous or cement mortar cushion as shown in Fig. 130*e*.

In one form of wood-block flooring a row of individual blocks 2 in. thick is dove-tailed to a 1-in. wood base, forming a strip whose width is equal to the length of the blocks and whose length is 8 ft. as shown in Fig. 130*f*. These strips are grooved on the sides to receive hardwood splines as shown. In this way several blocks are laid at a time, and all of the blocks are fastened together. This type of flooring may be blind-nailed to wood joists or nailing strips spaced about 16 in. on concrete, or to treated wood sleepers which are embedded in concrete; or it may be

laid on a thin bituminous cushion on concrete. In the latter case the blocks have holes bored laterally 8 in. to 12 in. apart, and a special nail is used in these holes to draw each strip tightly against the adjoining strip. If laid over wood joists a diagonal wood sub-floor should be used.

**Uses.** — Matched wood floors are warm and elastic so are not tiresome to work on. They are clean and, if proper selection is made, they are durable. Wood finished floors supported by fireproof construction are used in many buildings classed as fireproof because under these conditions they would burn very slowly in case of fire. They are not used in the highest grade of fireproof buildings where all wood is excluded.

Wood-block flooring is easy to work on, quiet and very durable. It is not attractive, and is only suitable for use in industrial buildings and warehouses where it will be subjected to severe traffic. Wood-block floors of redwood may be sanded and polished to form a satisfactory floor for schools, stores, and office buildings.

## ARTICLE 50. CONCRETE AND TERRAZZO FLOORS

**Concrete.** — Concrete wearing surfaces are used very widely where the structural part of the floor is of concrete. The wearing surface may be an integral part of the construction beneath, or it may be added as a separate layer. If the wearing surface is placed before the base has set, a thickness of $\frac{1}{2}$ in. to $\frac{3}{4}$ in. is satisfactory, but if placed after the base has set, the thickness should be $1\frac{1}{2}$ in. to 2 in., and the surface of the base should be roughened, thoroughly cleaned, and coated with cement grout just before the wearing surface is placed. This is done to secure a bond between the wearing surface and the base, but the results are uncertain.

The wearing surface which is an integral part of the floor may be considered as contributing to the strength of the structure, whereas a wearing surface which is added cannot be so considered and its weight increases the dead load which must be carried by all of the beams, columns, and foundations. In spite of this disadvantage a separate wearing surface may be cheaper than the integral wearing surface for it is placed after the rough work on the building has been completed, and does not need to be protected as carefully as the integral surface. The conditions which exist while the structural part of the floor is being placed are such that the accuracy required of a finished floor is difficult and expensive to secure.

A truer surface can be secured with the separate wearing surface as the deflection due to the weight of the floor and the yielding of the forms has occurred before the surface is placed, and any discrepancies can be taken up in the wearing surface. The separate wearing surface is sometimes

made thick enough to permit the placing of electrical conduits, plumbing pipes, etc., on top of the structural slab. This is a great convenience, but requires considerable extra material and a more substantial design.

The coarse aggregate is excluded from the wearing surface, and a richer mixture than that used in the structural parts is used. The sand grains and not the cement resist the wear, so the sand should have a high resistance to abrasion. Beyond a certain limit an increase in the amount of cement reduces the wearing qualities of a surface and increases the tendency to crack. Usually the mixture for the wearing surface consists of one part of cement to not less than two, or more than three, parts of sand.

Cement wearing surfaces must be very carefully laid using a minimum amount of water, troweling as little as possible, and protecting against drying out for at least ten days. Floor surfaces which have been improperly placed will constantly give off a dust which is objectionable. This is called "dusting" and may be prevented or remedied more or less effectively by the use of floor hardeners and other preparations for that purpose, or by painting.

Painted surfaces are satisfactory when the amount of wear is small, but where subjected to severe use frequent painting is required. Special paints are manufactured for use on cement floors. A cement colored paint, of course, shows the wear less than any other color.

Cement wearing surfaces are sometimes colored and marked off to imitate tile. Colored cement floors finished with wax may be made very attractive.

If artificial coloring matter is used, only those mineral colors should be employed which will not appreciably impair the strength of the cement.

Mineral coloring material is preferred to organic coloring material, because the latter fades more than mineral colors and may seriously reduce the strength of concrete. Mineral coloring may reduce the strength of concrete somewhat, but where the quantities used are less than 5 per cent this is not serious. The use of colored aggregates is preferable in obtaining color effects, the surface of the floor being brushed or ground to expose the aggregate.

Cement floors are inelastic and cold and tiresome to work on, but they are very durable if well constructed, are easily cleaned and are relatively inexpensive. Cement wearing surfaces should not be used over wood sub-floors without taking special precautions to prevent cracking. The construction should be similar to that used for tile floors as shown in Fig. 127*b*.

A cement wall base is very commonly used with cement floors. If a

separate wearing surface is used the wall base may be placed at the same time as the wearing surface with a curving fillet at the junction. This facilitates cleaning. A cement base will not adhere to lime plaster, hard wall plaster, gypsum blocks, Keene's cement, or plasterboard. The backing should be brick, stone, hollow tile, concrete or metal lath.

A cement floor is sometimes called upon to serve the double purpose of a floor and a roof. Under these conditions, a built-up roofing as described in Article 62 is placed on the structural slab. A wearing surface consisting of a concrete slab about 3 in. thick, is placed over this roofing and is divided into sections not over 16 ft. square by expansion joints about $\frac{3}{4}$ in. wide with a bituminous filler.

**Terrazzo.** — Terrazzo wearing surfaces are constructed in a manner similar to concrete wearing surfaces but a special aggregate of marble chips or other decorative material is always used and this aggregate is exposed by grinding the surface. The marble chips may be used in the entire top surface or they may be sprinkled over the surface of fresh mortar and be pressed or rolled in.

If the special aggregate is to be mixed in the mortar of the wearing surface the procedure is as follows:[1]

> Terrazzo finish shall be made by mixing 1 part of cement, $2\frac{1}{2}$ parts of crushed marble, or other stone or crushed pebbles, as may be called for by the plans, and sufficient water to produce a dense concrete. The concrete shall be spread on the base course and worked down to a thickness of 1 in. by patting or rolling and troweling. The marble shall all pass a $\frac{1}{2}$-in. screen and be free from dust. The surface shall be kept wet for not less than ten days, and after curing shall be rubbed to a plane surface with a stone or a surfacing machine.

If the special aggregate is to be sprinkled over the surface of the fresh mortar the procedure is as follows:[1]

> Terrazzo finish shall be made by mixing 1 part of cement, 2 parts of sand and sufficient water to produce a plastic mortar, which shall be spread on the base course to a depth of 1 in. Crushed marble, free from dust and passing a $\frac{1}{4}$-in. screen, shall be sprinkled over the surface of the fresh mortar and pressed or rolled in. The surface shall be kept wet for not less than ten days and after curing shall be rubbed to a plane surface with a stone or a surfacing machine.

If the base has set before the wearing surface is placed the hardened surface of the base is roughened with a pick or other effective tool and further prepared to receive the wearing surface as follows:[1] "The roughened surface shall be thoroughly saturated with water and covered with a thin layer of neat cement paste immediately before the wearing

[1] 1924 Report of the Joint Committee on Concrete and Reinforced Concrete.

surface is placed." This treatment is to insure the bonding of the wearing surface and the base.

Some architects specify a $\frac{1}{4}$-in. sand cushion covered with a layer of roofing paper to be laid on the structural slab before the terrazzo wearing surface is placed. In this case the wearing surface should be at least $1\frac{1}{2}$ in. thick. By making the wearing surface independent of the base the tendency to crack is supposed to be reduced.

This type of floor is more expensive than concrete and less expensive than tile or marble. It is used for floors of buildings where an attractive and durable floor is desired, but is inelastic and cold. The greatest objection to terrazzo floors is their tendency to crack. This objection has been overcome by the use of brass strips dividing the wearing surface into blocks whose greatest dimension is two or three feet. These strips can be arranged to form patterns and the color of adjacent blocks may be made different if desired.

Terazzo is not used directly over a wood sub-floor. If placed over wooden construction it should have a base similar to that used for tile floors as shown in Fig. 127*b*.

A terrazzo wall base is commonly used with terrazzo floors. It is usually made in the form of a sanitary cove base, the angle between the floor and the wall having a fillet to facilitate cleaning. A terrazzo base will not adhere to lime plaster, hardwall plaster, gypsum blocks, or plaster board. The backing should be brick, stone, concrete, hollow clay tile, or metal lath.

## ARTICLE 51. MAGNESITE COMPOSITION AND ASPHALT MASTIC FLOORS

**Magnesite Composition.** — A large number of magnesite composition floors are on the market. In some the materials are furnished by the manufacturers to be laid with local labor, while in others the material and labor are furnished by the manufacturers.

In general, magnesite composition floors consist of a dry mixture of magnesium oxide, asbestos or other inert material, and a pigment to which liquid magnesium chloride is added on the job to form a plastic material which is troweled to a smooth finish and sets hard in a few hours. Magnesium chloride in the powdered form may be included with the magnesium oxide and other materials, in which case it is only necessary to add water on the job.

Magnesium oxide is obtained by calcining magnesite which is magnesium carbonate, carbon dioxide being driven off in the process. When magnesium chloride is added to magnesium oxide a cementing material known as magnesium-oxy-chloride is formed. This is the cementing

material in magnesite composition floorings, the asbestos being the inert aggregate. Asbestos is chosen on account of its toughness and cushioning effect.

The finished surface is usually $\frac{1}{2}$ in. thick, but floors as thick as $1\frac{1}{2}$ in. are used. Magnesite flooring may be applied to a sub-floor of wood, concrete, or steel plates. If the sub-floor is wood a base course or foundation is required in which metal lath or wire mesh is placed to prevent cracking.

A wall base of the same material may be placed at the same time as the floor, and be made monolithic with it, and with a rounding corner between the two forming a sanitary base which is easily cleaned. This base should not be applied over hardwall plaster, Keene's cement, gypsum blocks, or plaster board as it will not adhere to these surfaces. It will adhere to hollow clay tile, brick, stone, or concrete masonry, and wood or metal lath. Metal lath should preferably be galvanized.

This type of floor is less attractive and less durable than clay tile, terrazzo, and marble, but is more comfortable to work on and less noisy than these floors. It is waterproof, easily cleaned, and fire-resistant.

Magnesite composition is suitable for foot traffic, and is appropriately used on floors of hospitals, schools, office buildings, toilets, kitchens, bathrooms, etc.

**Asphalt Mastic.** — The term asphalt mastic is applied to two classes of floors which are very different in composition, properties, and use. In both the cementing material is asphalt, but in one it is mixed hot with sand or crushed rock, and laid hot in a continuous sheet 1 to 2 in. thick, or pressed into blocks. In the other it is fluxed with a mineral oil, mixed with asbestos, and applied cold with a trowel in four or five coats, building up to a total thickness of $\frac{1}{8}$ to $\frac{1}{4}$ in. The first is used in industrial buildings, and will withstand heavy traffic such as trucking, whereas the second is used in office buildings, schools, etc., and is only suitable for foot traffic.

The heavy asphalt mastic floors consist of natural asphalt, crushed rock, and a fine aggregate of sand or crushed rock screenings. They may be placed in a sheet or in blocks. Sheet asphalt floors are mixed and placed at a temperature of about 300 deg. fahr. and are rolled to form a compact layer with an even surface. They may be as thin as 1 in. for foot traffic only, but should be $1\frac{1}{2}$ to 2 in. thick for heavy traffic. The base may be either wood or concrete. If the base is of wood a layer of building paper is placed on the base before the asphalt is placed. Asphalt mastic blocks are made at the factory and shipped to the building. In making these blocks they are subjected to a very heavy pressure. The blocks are 4 or 5 in. wide, 8 or 12 in. long, and $1\frac{1}{4}$, 2, and $2\frac{1}{2}$ in. thick.

If laid on a concrete base the blocks are set in cement mortar. The joints are filled with fine sand, hot liquid asphalt, or grout.

These heavy asphalt mastic floors are elastic, dustless, durable, and water and acid proof. They are used in factories, warehouses, loading platforms, damp-proof cellars, swimming pools, hotel kitchens, etc., and on floor surfaces which are out-of-doors.

Light asphalt mastic flooring is composed of asphalt, for a cementing material, fluxed with mineral oil and mixed with an inert material, usually asbestos fiber and a pigment. It is placed cold in four or five coats with a trowel over a concrete or wood base, and has a total thickness of $\frac{1}{8}$ to $\frac{1}{4}$ in. The thin coats are used so that each coat may dry out and harden before the next is placed. The common colors are green, red, brown, and black. A sanitary cove wall base may be made monolithic with the floor surface, but it is first necessary to provide a foundation, which, when the thin layer of mastic is applied, will give a base of the desired shape.

Light asphalt mastic resembles linoleum in its appearance, and in some of its properties, but it is less absorbent and more acid proof. It is warm and comfortable to work on, and is easily cleaned. This type of flooring is used in office buildings, hospitals, schools, bathrooms, damp cellar floors, etc., and may also be used outdoors on the floors for roof gardens and porches. It is not suitable for use where it will be subjected to the action of oil and grease, and will not withstand heavy trucking.

Light asphalt mastic flooring is also manufactured in sheets $\frac{1}{8}$, $\frac{3}{16}$, and $\frac{1}{4}$ in. thick, ready for placing. These sheets have the same composition and use as the material just described, but have the advantage of ease in placing. The joints are made with the same material in plastic state and repairs are also made with this material.

## ARTICLE 52. TILE AND BRICK FLOORS

A great variety of tile of various materials and shapes are used for wearing surfaces for floors. Hard surfaces are obtained with clay tile, marble, terrazzo tile, and slate, while elastic surfaces are obtained with cork tile, linoleum tile, and rubber tile.

**Tile Setting or Placing.** — Clay, marble, terrazzo, and slate tile are always set in portland cement mortar when used on the interior of buildings, but quarry tile, promenade tile, and slate may be set in asphalt when used on roof gardens or in similar positions where a watertight floor is required. In this case they usually take the place of gravel on tar-and-gravel roofs.

These hard tile are always set in a concrete slab foundation or base, so

wood floors must be specially constructed to receive this base as shown in Fig. 127*b*. A wood sub-floor is placed on the wood joists about 3 in. below the finished floor level. On this sub-floor a concrete slab, preferably reinforced, is placed. The top of the concrete should be kept low enough to allow for the tile, and the mortar in which they are set.

The elastic tile referred to above are cemented to concrete or matched wood floors. Some manufacturers prefer that wood floors be covered with a cotton fabric securely tacked in place, and that the tile be cemented to the fabric.

**Clay Tile.** — Clay tile are more common than any other type. They are made by burning special clays or mixtures of clays which have been pressed into the desired shape. Two different processes are used: the Plastic Process and the Dust-pressed Process.

In the *plastic process*, the clays are mixed with water and run through pugging machines until a uniform plastic consistency is secured. They are then pressed by hand or machine in dies or molds, and after drying are burned in kilns. The plastic nature of the materials has a tendency to produce tiles which are slightly irregular in shape.

In the *dust-pressed process*, the clays after being finely ground and mixed with water, are passed into filter presses where the excess water is pressed out. The resulting mass is dried, pulverized, pressed into shape in metal dies, and burned in kilns.

The production of special sizes and shapes in the dust-pressed process involves special dies and handling, and is a deviation from the regular routine of manufacture. In plastic process special sizes and shapes may be produced without distinct departure from the methods of production common to the regular tile.

Clay tile may be glazed or unglazed. For use in residences, all types of floor glazes are sufficiently durable for floors, but for public buildings subjected to severe traffic a special high-fire type of glaze is available.

The colors in unglazed tiles are produced either by the selection of clays which will burn to the desired colors, or by the addition of certain materials such as the oxides of cobalt and chromium. Some clays and color ingredients can be fired to complete vitrification, producing vitreous tile, while others will not stand this high temperature and produce semi-vitreous tile. A great variety of colors and textures are available.

Unless otherwise noted the various types of vitreous tile are obtainable in the following colors: white, celadon, silver gray, green, blue-green, light blue, dark blue, pink, cream, and granites of these colors. The semi-vitreous tiles are available in buff, salmon, light gray, dark gray, red, chocolate, black, and the granites of these colors. The term granite means a mottled color resembling granite.

The most common shapes of tile are square, rectangular, hexagonal, octagonal, triangular or round, and the sizes vary from $\frac{1}{2}$ in. to 12 in., and the thickness from $\frac{1}{4}$ in. to $1\frac{1}{2}$ in. Trim tile are available for use as wall base or to meet any other decorative or utilitarian demands.

Various names are given to the tiles of different sizes and shapes. The more common types used for floor surfaces are the following: *Ceramic mosaic* which includes unglazed dust-pressed tile $\frac{1}{4}$ in. thick, and with an area of less than $2\frac{1}{4}$ in. They are vitreous or semi-vitreous, depending on the color, and may be square, oblong, hexagonal, or round. These tile usually are mounted with exposed face stuck to paper in sheets about 2 ft. by 1 ft., the paper being removed after the tile are set. If desired the tile can be obtained loose.

*Plastic mosaic* includes the same size and shape tile as ceramic mosaic, mounted or loose, but these tile are made by the plastic process, and the colors are those that result from the firings of natural clays.

*Cut mosaic* floors are made from unglazed, dust-pressed, vitreous or semi-vitreous strips, $\frac{1}{4}$ in. thick, and $\frac{1}{2}$ or $\frac{5}{8}$ in. wide, which are cut into the irregular pieces necessary in the production of ungeometric designs and pictorial work. These tile are furnished in loose strips, or are assembled in designs mounted with exposed face on paper which is removed after the tile are set.

*Vitreous tile* and *semi-vitreous tile* are names applied to unglazed, dust-pressed tile $\frac{1}{2}$ in. thick. These tile are vitreous or semi-vitreous depending on the color. They are furnished in the same shapes as ceramic mosaic, except round, but are larger, having an area of $2\frac{1}{4}$ sq. in. or greater, the largest vitreous tile being 3 in. square, and the largest semi-vitreous tile, 6 in. square.

*Paving tile* are unglazed, dust-pressed tile $\frac{3}{4}$ in. thick. Flint tile are vitreous paving tile, and the semi-vitreous are called *hydraulic tile.* These tile may be square, oblong, hexagonal, or octagonal. With the exception of the oblong tile the smallest sizes is $4\frac{1}{4}$ in. and the largest 6 in. Oblong tile vary in size from 6 in. by 3 in. to 10 in. by 5 in.

*Corrugated paving tile* are semi-vitreous, unglazed, dust-pressed paving tile $\frac{13}{16}$ in. thick, and 6 in. square with corrugated face.

*Rough red paving tile* are semi-vitreous, unglazed, dust-pressed tile, $\frac{1}{2}$ in. or $\frac{5}{8}$ in. thick, depending on the size, and 6 in. or 9 in. square with the corresponding oblong half tile.

*Inlaid or encaustic tile* are unglazed dust-pressed decorative tile, $\frac{1}{2}$ in. thick, produced by inlaying a figure or ornament of one or more colors into a body of a contrasting or harmonizing color before firing. They are vitreous or semi-vitreous according to colors.

*Quarry tile* are machine made unglazed tile, $\frac{3}{4}$ in. to $1\frac{1}{2}$ in. in thickness

made from common clays. They are always square, the common size being 6 in., 9 in., and 12 in. The colors may be various shades, plain red, or the following granites: red, light gray, dark gray, black, chocolate, light brown, dark brown, or green.

*Promenade tile* are machine made, unglazed tile, 1 in. thick, made from common clays. The size is always 6 in. by 9 in., and the color, some shade of red.

*Plastic tile* are unglazed tile made by the plastic process from natural clays. Any size or shape can be obtained. The thickness is $\frac{1}{2}$ in. or over, depending upon the size.

**Marble Tile.** — Marble floors are constructed of slabs of marble about $\frac{7}{8}$ in. thick. The standard sizes are 8 in. by 16 in. and 10 in. by 20 in. They are available in many colors. Patterns may be worked out with slabs of different sizes and colors. Different marbles vary greatly in their wearing qualities. Many wear too rapidly to give satisfactory service.

Marble mosaic floors consist of small pieces of marble grouped to form ornamental or figured compositions in the same manner that mosaic floors are made with clay tile. Marble mosaic floors are less durable than those formed of clay tile.

**Terrazzo Tile.** — Terrazzo tile are made of marble chips, sand, and portland cement, colored as desired, formed in molds, the surface being ground to expose the marble chips.

**Slate Tile or Flagging.** — Slate is used to a limited extent for interior floor surfaces and more extensively for exterior surfaces such as terraces and garden walks.

It may be obtained in various shades of gray, green, and purple, in random or regular sizes, with split or rubbed surface, and with rough trimmed or sawed edges.

**Other Natural Stones.** — Many natural stones are used in the same manner as slate and marble which have already been considered. The best known are probably bluestone and travertine.

**Carrara Glass, Vitrolite, and Opalite Tile.** — Tile made of glass of special composition and manufacture is on the market under such names as "carrara glass," "Vitrolite," and "Opalite." These tile may be obtained in various sizes and thicknesses. They are attractive, durable, and have about the same properties as clay tile. Glass of this kind is called structural glass. It is used for wainscoating, table tops, toilet stalls, and in other places where interior marble is used. Carrara glass is named after a well-known Italian marble which it is supposed to resemble. These glasses may be obtained in a polished or a honed finish.

**Cork and Linoleum Tile.** — Cork tile are made from pure cork shavings compressed in molds to a thickness of $\frac{1}{2}$ in., and baked. They are used over wood or cement floors to which they are cemented. Cork tile are elastic, noiseless, fairly durable, and quite absorbent. They are available in various shades of brown.

Linoleum tile are of the same composition as linoleum, and have the same properties and uses, but may be arranged in patterns to form a floor which may be more attractive than linoleum. They are cemented to a wood or concrete floor.

**Rubber Tile.** — Rubber tile are made of rubber combined with other substances such as cotton fiber, granulated cork, and asbestos fiber. They vary in thickness from $\frac{3}{16}$ in. to $\frac{1}{2}$ in. and are made in various colors, shapes, and patterns. Rubber tile are elastic, noiseless, durable, and easily cleaned, but are quite expensive.

**Wall Bases.** — Wall bases are available for use with clay, marble, cork, linoleum, and rubber tile.

**Uses of Tile Floors.** — The various forms of hard tile may be used where attractive, durable and easily cleaned floors are desired, and where an expensive floor is warranted. Promenade or quarry clay tile, or slate are probably the most suitable for exterior use, such as on terraces and roof gardens. These floors are cold and hard, so are tiresome to work on, and are too noisy to use in assembly rooms or libraries where movable chairs are used.



The elastic tile of various materials are less tiresome to work on than the hard tile, and are warmer and less noisy. In general, they are not as durable or as attractive as some of the forms of hard tile, but their elastic properties make their use desirable where a comfortable, noiseless, and reasonably attractive floor is desired.

**Cork Brick.** — Cork brick are made of granulated cork, and a binder compressed under heavy pressure to a thickness of $1\frac{3}{4}$ in. to 2 in. They are used where the floors are subjected to severe usage, and where the elastic properties of cork are desirable.

**Clay Brick.** — Clay brick are sometimes used for the wearing surface of ground floors in forge shops, round houses, warehouses, and other types of industrial buildings. Paving brick may be used, or one of the special forms of brick made for the floors of buildings. Brick floors are also used on porches and terraces and occasionally to secure certain effects in high-class buildings.

Brick should have a solid foundation of concrete or macadam. The brick wearing surface should be laid on a layer of sand $\frac{1}{2}$ in. to 1 in. in thickness, called a sand cushion. After the brick are laid the joints should have a filler of sand, cement grout, or bituminous material. The

brick may be arranged to form a great variety of patterns when decorative effects are desired.

Brick wearing surfaces will stand hard usage and replacements are easily made, but they are inelastic, cold to work on, and difficult to keep clean.

### ARTICLE 53. LINOLEUM, CORK CARPET, AND RUBBER FLOORS

**Linoleum.** — Linoleum is used as a covering for wood and concrete floors. In making linoleum, linseed oil is oxidized by exposure to the air into a tough, rubber-like substance which is mixed with ground cork, wood flour, coloring matter, and other ingredients, and the resultant plastic substance is pressed upon a backing of burlap. It is then passed into drying ovens where it is thoroughly cured and seasoned. There are three common types of linoleum: plain, printed or stamped, and inlaid. Linoleum is furnished in thicknesses varying from $\frac{1}{20}$ in. to $\frac{1}{4}$ in. in rolls usually 2 yd. wide but in some cases, 4 yd. wide.

Plain linoleum is a solid color throughout its entire thickness. It is furnished in several thicknesses, varying from $\frac{1}{12}$ in. to $\frac{1}{4}$ in., and in many colors. The thicker grades are known as battleship linoleum, and are the most satisfactory grades for heavy traffic.

Stamped or printed linoleum has a pattern printed on the surface with oil paint. It varies in thickness from $\frac{1}{20}$ to $\frac{1}{12}$ in. and is satisfactory for light service only, as the pattern wears off in time. After the pattern shows wear, the linoleum is still serviceable, but is unattractive. Occasional varnishing will preserve the pattern.

Inlaid linoleum consists of small units of linoleum of various colors arranged in patterns and pressed on a burlap back. The color of each unit is constant throughout the entire thickness so the pattern remains as long as the linoleum lasts. Inlaid linoleums are furnished in thicknesses varying from $\frac{1}{12}$ in. to $\frac{1}{8}$ in. They are used in kitchens, and toilets, and will give satisfactory service wherever their use is appropriate.

The best method of laying linoleum is to paste a layer of heavy unsaturated felt paper to the concrete or wood floor, and then cement the linoleum to the felt. Linoleum is often cemented directly to the concrete or wood floor, but with less satisfactory results than with the above method. Linoleum is sometimes tacked to wood floors. This method is very unsatisfactory.

When a suitable linoleum is properly laid it will last for many years. It is sanitary, easily cleaned, resilient, warm, and attractive. Considering the length of life and satisfactory service it may be considered an inexpensive floor covering. Linoleum should not be used in basements

unless the floors and walls are waterproofed. A special cove wall base is available for use with linoleum.

Linoleum floors are commonly used without any surface treatment but if plain and inlaid linoleums are waxed, and stamped linoleums are varnished, as often as the use requires, the floors will be more easily cleaned and will last longer.

**Cork Carpet.** — Floors of wood or concrete may be covered with cork carpet, which is a covering similar to linoleum, and is laid in the same way. It is composed of the same material; oxidized linseed oil, ground cork and wood flour, pressed to a burlap back, but is not subjected to as great pressure as linoleum, so is more resilient and porous, and less durable. Cork carpet is $\frac{1}{4}$ in. thick, and is furnished in rolls 2 yd. wide. Many colors are available.

To secure the best service cork carpet should be laid by first pasting a layer of unsaturated felt to the wood or concrete floor, and then cementing the cork carpet to the felt. Cork carpet is often cemented directly to wood or concrete, and is sometimes tacked to wood floors. The latter method is particularly unsatisfactory.

Cork carpet makes a very quiet floor covering, and is more elastic but less durable and more absorbent than linoleum. It is particularly suitable for use in churches, theaters, public libraries, and other places where a noiseless floor covering is essential. Cork carpet should not be used in basements where the floor and walls are not waterproofed.

## ARTICLE 54. SELECTION OF WEARING SURFACE

The selection of a proper floor surface is one of the most important and, at the same time, one of the most difficult problems which arise in the construction of a building. The appearance, usefulness, and cost of upkeep of a building are greatly affected by the type of floor which is installed. Considering the importance of the subject it is unfortunate that it is not possible to devise a satisfactory basis of selection.

The report of the Committee on Floors of the American Hospital Association has been of considerable value in preparing this article. The definitions of the properties of floor surfaces follow those of the Committee quite closely.

The following discussion of the relative merits of the various floor surfaces is prepared, realizing that the value of such discussion is limited because of the great variations in the materials and workmanship, and in the kind of usage and care a floor will receive.

Floors which are manufactured complete and ready for installation, such as tile, linoleum, and rubber, will show less variation in quality

than such floors as terrazzo, concrete, and magnesite composition which are manufactured on the job, and are not subject to as rigid control as factory-made products. Natural flooring materials such as marble and slate are also quite variable in quality.

Each property of a wearing surface will be discussed and an attempt will be made to classify roughly the various materials according to the degree to which they possess that quality.

**Appearance.** — Appearance is the attractiveness of the material, its color range, texture, and its decorative value in an architectural sense.

There are many floor surfaces which are attractive when suitably used, such as hardwood when properly finished, terrazzo, clay tile, marble, and to a less degree rubber tile, cork tile, and linoleum tile. Materials which might be considered neutral in appearance are linoleum, cork carpet, sheet rubber, slate, and composition. Concrete without special treatment, heavy asphalt mastic, and wood blocks are not suitable for use where appearance is a factor. Concrete floors may be painted or waxed, and are not unattractive as long as the surface is maintained, but this is difficult to do where the traffic is at all heavy.

**Durability.** — Durability may be defined as the resistance to wear, temperature, humidity changes, decay, and disintegration. The adhesion of a material to its base is also a factor in durability.

The most durable floor surfaces for foot traffic are clay tile, terrazzo, slate, and concrete, but terrazzo floors are very likely to crack if not divided into blocks by brass strips or laid in the form of tile. Marble is widely used in floors subject to severe wear, but it does not stand up as well as the materials just mentioned. Concrete surfaces to be durable must have durable aggregates.

Hardwood, linoleum, linoleum tile, and rubber tile give very satisfactory service whereas cork carpet, cork tile, and magnesite composition and light asphalt mastic are not unsatisfactory.

With the exception of concrete none of the materials mentioned so far is suitable or satisfactory for heavy traffic, such as trucking. Brick, wood blocks, and heavy asphalt mastic may be used under these conditions. Heavy maple flooring may also be satisfactory.

**Comfort.** — Comfort under foot is determined by the shock-absorbing qualities, sure-footedness, evenness of surface, and conductivity. A floor which is a good heat conductor will always feel cold.

The most comfortable floors to work on are cork tile, cork carpet, and rubber. Wood, linoleum, magnesite composition, and light or heavy asphalt mastic are very satisfactory, but concrete. terrazzo, clay tile, marble, slate, and brick are tiresome and cold

**Noiselessness.** — Cork tile, cork carpet, and rubber are practically noiseless; wood, linoleum, magnesite composition, and asphalt mastic are somewhat less satisfactory; but concrete, clay tile, marble, slate, and brick are the most noisy of flooring materials.

**Fire Resistance.** — Materials may be non-combustible, but still suffer severely in case of fire.

Concrete, clay tile, and brick are probably the most fire-resistant floor surfaces, but terrazzo, marble and slate should be very satisfactory. Magnesite composition and asphalt mastic will not burn, but may suffer seriously in a fire. Linoleum, cork carpet, rubber and wood are combustible, but if laid on a fireproof base they are not considered a serious defect in a fireproof building.

**Sanitation.** — To be sanitary a floor surface must be non-absorbent, and easily cleaned. Joints which are not watertight are an unsanitary feature.

The most sanitary floor surfaces are terrazzo, clay tile, marble, and slate. Magnesite composition, asphalt mastic, rubber, and linoleum are quite satisfactory. Cork carpet is unsatisfactory on account of its porosity, concrete on account of the difficulty in cleaning, and wood on account of its porosity and the presence of open joints.

**Acid and Alkali Resistance.** — The factors which should be considered under this heading are immunity from damage by occasional spillings of strong acid solutions and resistance to the continuous use of soap, lye, cleaning and scouring compounds, and disinfectants.

Clay tile is the most satisfactory floor surface in this respect; heavy and light asphalt mastic are quite resistant; rubber, terrazzo, marble, concrete and magnesite composition are sufficiently resistant for ordinary purposes; but linoleum, cork carpet, and cork tile should not be subjected to the action of acids and alkalies.

**Maintenance.** — This heading includes such items as the ease with which a flooring is cleaned, the necessity for care and surface treatment, such as waxing and painting, the necessity for repairs, and the cost of such operations.

Tile, marble, terrazzo, slate, and rubber tile floors are easily cleaned and require very little care. Linoleum and magnesite composition are easily cleaned, but should receive surface treatment occasionally. Cork carpet is not easy to clean, and requires surface treatment. Hardwood floors are fairly easy to clean if in good condition, but require frequent surface treatment. Concrete is not as easy to clean as tile, linoleum, etc., if it is not painted or waxed. Painting makes cleaning easier, but requires frequent renewal. Light asphalt mastic is easily cleaned, and requires no surface treatment.

The monolithic floors such as terrazzo, magnesite composition, and concrete are difficult to repair satisfactorily. Floors composed of separate units of tile, slate, or marble are more easily repaired, but require skilled mechanics. Linoleum, cork tile, and cork carpet may be easily repaired by replacing the damaged parts. Light asphalt mastic can be easily repaired by patching.

The maintenance costs of wood blocks, heavy asphalt mastic, brick, and concrete are relatively low except under extremely severe traffic. With the exception of concrete these materials are easily repaired. They receive no surface treatment.

**Initial Cost.** — One of the first factors which must be considered in selecting a floor surface is the initial cost, but even the most expensive materials do not possess all of the features which are considered desirable.

Flooring materials may be roughly divided into classes according to their cost in place. In the following list the most expensive materials are given first:

1. Clay tile, marble, and rubber tile.
2. Terrazzo, magnesite composition, cork tile, and hardwood.
3. Cork carpet, linoleum, light and asphalt mastic, and slate.
4. Concrete.

This list assumes that a concrete base is available to receive the wearing surface. Hardwood is included among the more expensive materials on account of the cost of nailing-strips and concrete fill required.

If the wearing surface is to be applied to wood floor construction the order would be somewhat changed, for a concrete base would have to be provided for clay tile, marble, terrazzo, slate, and concrete, whereas the other materials may be applied directly to the wood. In this case the relative costs would be somewhat as follows:

1. Clay tile, marble.
2. Terrazzo.
3. Rubber tile.
4. Magnesite composition, and cork tile.
5. Cork carpet, linoleum, light asphalt mastic.
6. Hardwood.

Brick, wood block, and heavy asphalt mastic floors are not included in these lists, for they are used for a different class of traffic than that to which the materials included (except concrete) are subjected, so a comparison would be of no value.

**Weight.** — The heavier floor surfaces add indirectly to the cost by requiring stronger floor construction, beams, girders, columns, and

foundations. Clay tile, marble, and slate are bedded on $\frac{1}{2}$ in. or more of cement mortar which has no structural value, terrazzo requires 1 in. of material which is simply a dead weight, and hardwood flooring requires about 2 in. of filling between the nailing strips. Rubber tile, magnesite composition, cork tile, cork carpet, linoleum, light asphalt mastic, and concrete do not require this additional material. This additional weight exists when the structural floor is some form of concrete slab, but may not be a factor in hollow tile arch construction where a certain amount of filling is necessary regardless of the wearing surface.

## REFERENCE

Sweet's Architectural Catalogue, published by the F. W. Dodge Corporation, New York City, contains the advertisements of various manufacturers of floor surfacing materials in convenient form for reference.

## CHAPTER X

# ROOF CONSTRUCTION AND ROOFING MATERIALS

### ARTICLE 55. TYPES OF ROOFS

Roofs of buildings are divided into various types, depending upon the shape.

*Flat roofs* as shown in Fig. 131*a* are very extensively used on all kinds of buildings. They are sloped from $\frac{1}{2}$ in. to 1 in. vertical to 12 in. horizontal to insure proper drainage. Some designers make roofs without any slope whatever considering that watertight roofs can be secured without any slope and the construction is simplified.

Roofs which slope in one direction only as shown in Fig. 131*b* are called *shed roofs.* This type of roof is used on temporary structures where appearance is not considered, or in connection with other types as shown in Fig. 131*c* to form a lean-to.

*Gable roofs* slope in two directions as shown in Fig. 131*d*. This type of roof is very widely used, especially on residences. The slope is often as flat as 4 in. vertical to 12 in. horizontal, and as steep as 20 in. vertical to 12 in. horizontal, but the most common slopes are between 6 in. vertical to 12 in. horizontal, and 12 in. vertical to 12 in. horizontal.

*Hip roofs* slope in four directions as shown in Fig. 131*e*. This type of roof is very widely used. The same slopes are used on hip roofs as on gable roofs.

*Gambrel roofs* slope in two directions, but there is a break in the slope on each side as shown in Fig. 131*f*. The gambrel roof is very popular for residences on account of its attractiveness, and the efficient use which may be made of the space under the roof, especially when a long shed dormer as shown in Fig. 132*a* is used. *Mansard roofs* slope in four directions, but there is a break in each slope as shown in Fig. 131*g*. *Deck roofs* slope in four directions, but have a deck at the top as shown in Fig. 131*h*.

The various types of *roof dormers* are shown in Fig. 132*a*.

The *saw-tooth roofs* shown in Fig. 132*b* and 132*c* are used quite extensively on industrial buildings on account of the advantages they offer in light and ventilation. The steep face of Fig. 132*b* and the vertical face of Fig. 132*c* are entirely of glass and are usually turned towards the north, the light from that direction being more nearly constant throughout the day than light from other directions and the glare of direct sunlight is

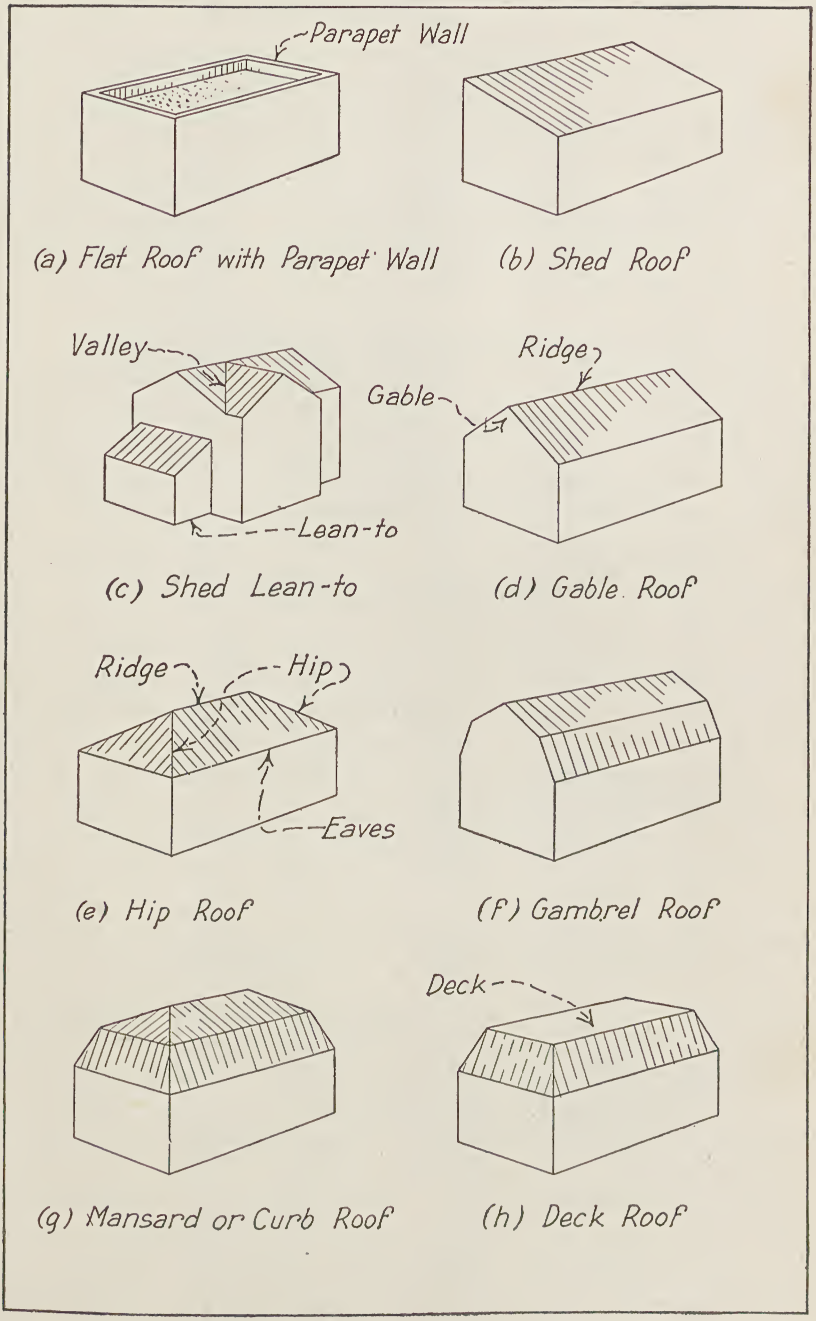


FIG. 131. Types of Roofs

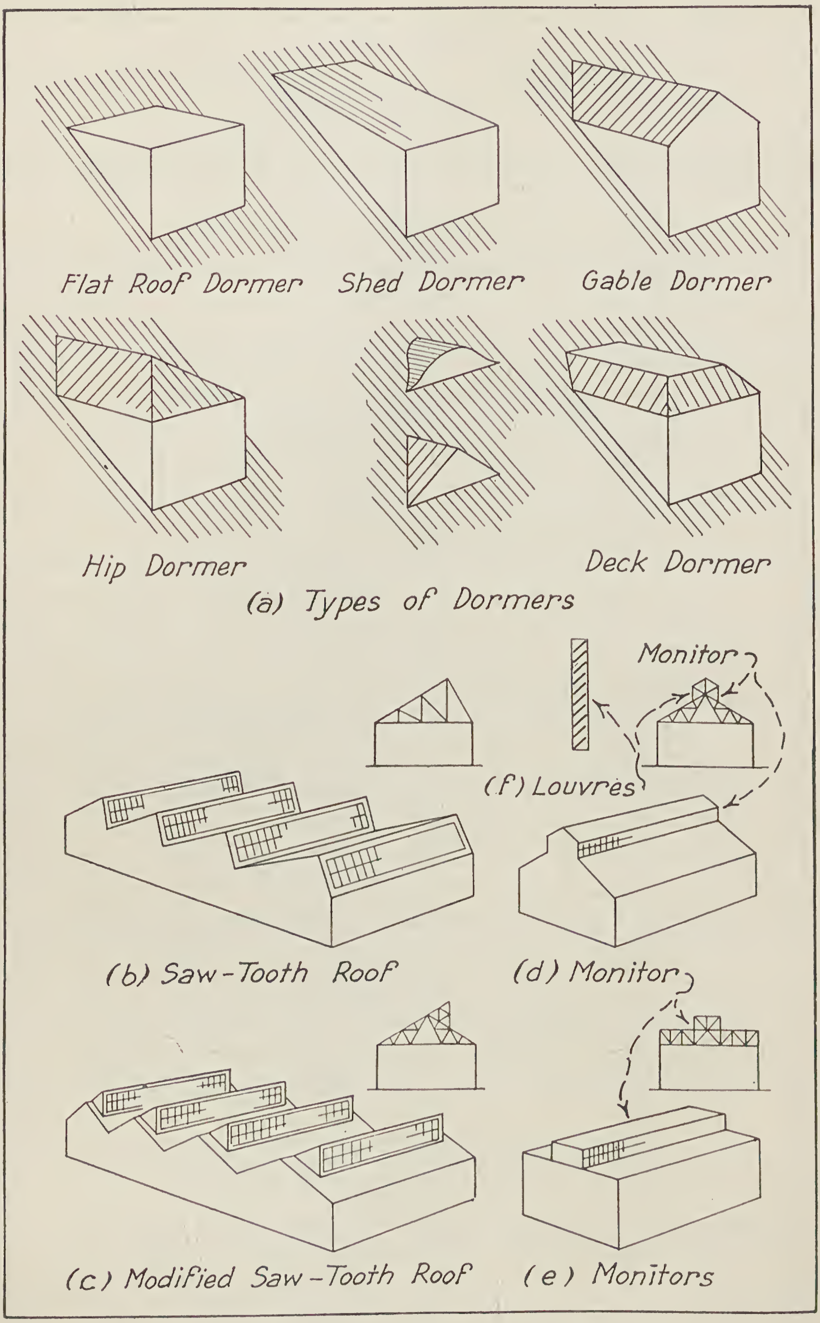


FIG. 132. Types of Dormers and Roofs

avoided. The type shown in Fig. 132*c* does not have as large an area of glass as that shown in Fig. 132*b* but is more easily made watertight in the valley. At least a part of the windows are arranged to open for ventilation. This is commonly the upper half.

The parts of a roof such as *ridge*, *hip*, *valley*, *gable*, and *eaves* are indicated in Figs. 131*a* to *h*. *Monitors* as shown in Figs. 132*d* and 132*e* are used extensively to secure better light or ventilation. The vertical face is called the *clerestory*. If ventilation only is desired, louvres may be used in the clerestory as shown in Fig. 132*f*.

## ARTICLE 56. ROOF CONSTRUCTION

**Types of Roof Deck.** — Nearly all forms of roof covering should have continuous surfaces to support them. Included in this group are shingles of various materials, nearly all forms of tile, slate, sheet metal, built-up roofings such as tar and gravel, and prepared roofings. Wood shingles, tile, and slate can be laid on widely spaced sheathing or on narrow slats, one slat being required for each row of shingles, tile, or slate.

In damp climates, the use of slats to support wood shingles may be desirable because the shingles can then dry out from the under side and do not decay or tend to cup and crack as badly as on solid decks. These advantages may be more than offset by the decreased fire resistance and increased heat loss. In general, the solid deck is to be preferred, especially in the case of tile and slate where roofers' felt is used under the tile or slate to provide against leaks due to breakage or from other causes.

Corrugated sheets of steel, zinc, asbestos board, or glass will span distances of 4 or 5 ft. between purlins, and do not require sheathing. Some forms of cement tile are designed to rest directly on purlins spaced 4 or 5 ft. apart.

The solid roof deck supporting the roof covering may be of the following types of construction:

Wood sheathing 1 in. thick supported on rafters for sloping roofs or joists for flat roofs spaced 12 or 16 in. apart and usually of 2-in. material, as shown in Figs. 70, 71, 80, 81, 82, 83, and 133*a*. This sheathing may have square edges or may be matched or ship-lapped.

Heavy wood sheathing from 2 to 6 in. thick supported on purlins for sloping roofs or on roof beams for flat roofs, spaced from 4 to 12 ft. or more apart, as shown in Figs. 84 to 86. The sheathing may be matched or may have a loose tongue or be laminated as shown in Figs. 127*f*, *g*, and *h*.

Reinforced-concrete solid or ribbed slabs supported on steel or reinforced-concrete beams as shown in Figs. 118*b* and *c*, 120*a* to *f*, 121*a* to *c*, 122, 124, and 128.

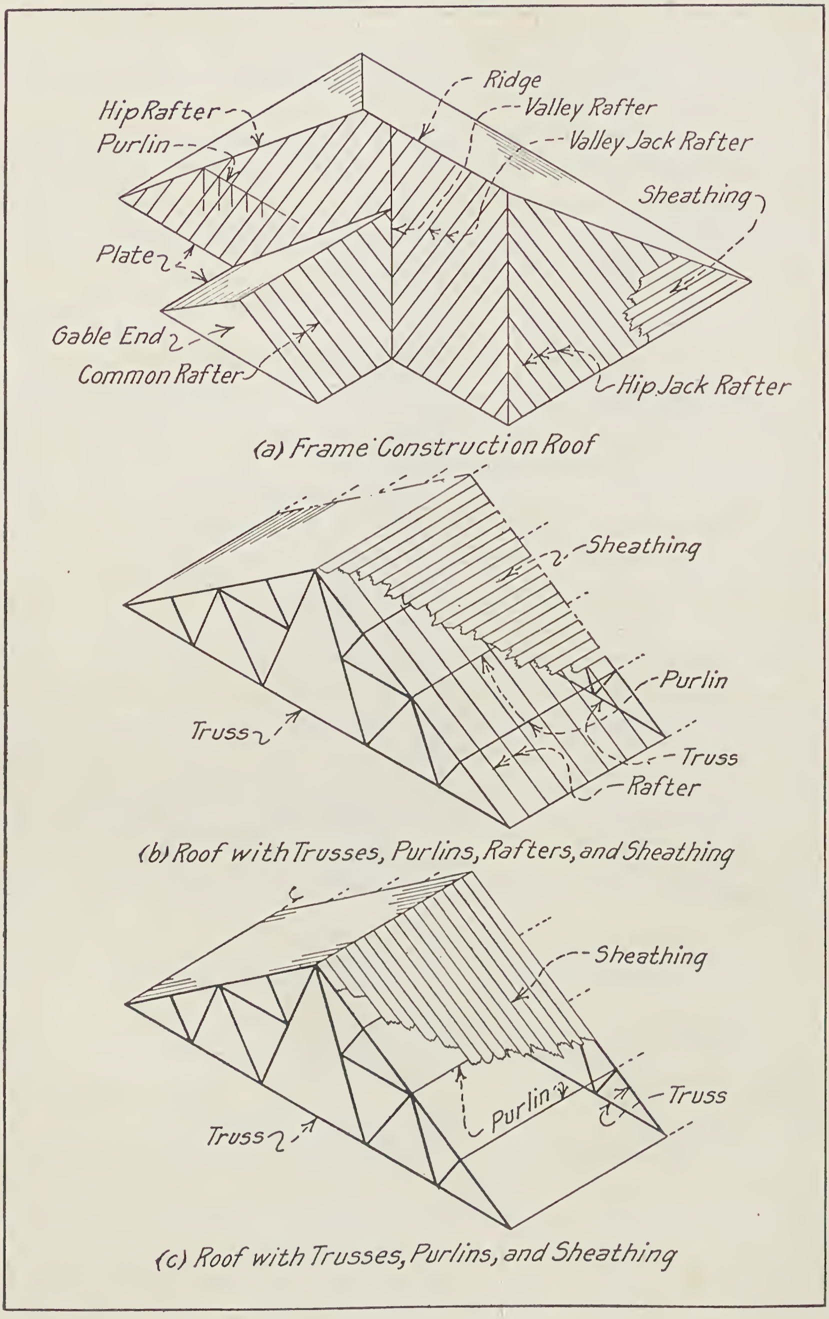


Fig. 133. Roof Framing

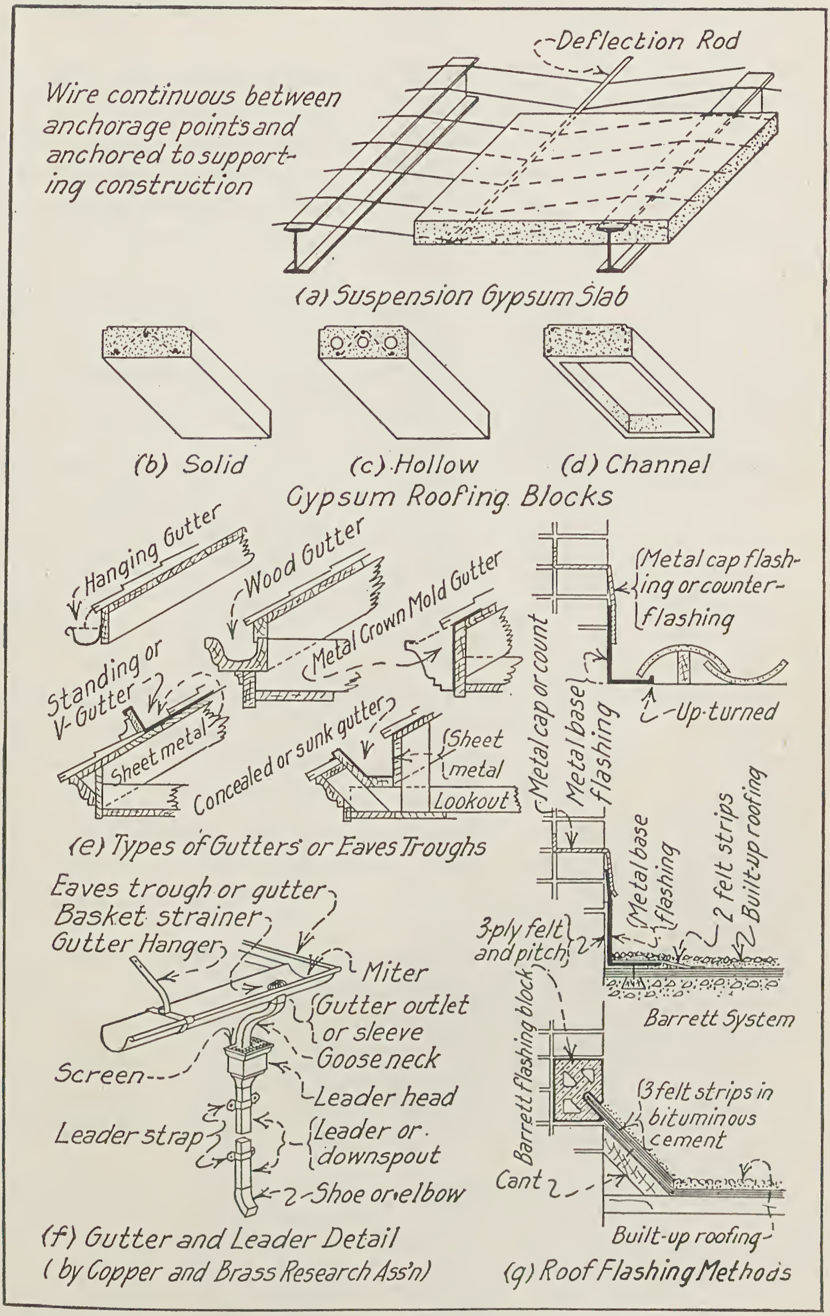


Fig. 134. Roof Construction and Drainage

Cast-in-place gypsum slabs supported on steel beams as shown in Fig. 134*a*.

Precast gypsum slabs as shown in Fig. 134*b*, *c*, and *d*. The solid and hollow slabs are 12 in. wide and 30 in. long. They are supported on steel rafters consisting of inverted T-sections, spaced $30\frac{3}{4}$ in. center to center. The rafters are supported by purlins spaced from 5 to 8 ft. apart depending upon the size of the rafter and the load on the roof. The channel slabs are supported directly on purlins spaced up to $6\frac{1}{2}$ ft. apart.

Precast cement slabs 2 ft. wide, and $1\frac{1}{4}$ in. thick designed to be supported on steel beams spaced not over 5 ft. apart.

Precast cement slabs with channel-shaped sections, similar to Fig. 134*d*, 18 in. wide, and $3\frac{1}{2}$ or 4 in. deep designed to be supported on steel beams not over 10 ft. apart.

Sheet-steel decks with ribs formed on the lower side to give strength and rigidity, supported by steel or wood beams or purlins, spaced up to 10 ft. apart, to which they are fastened by clips. If a sheet-steel deck is used on a building which is to be heated in winter or which must not be excessively warm in the summer insulation must be used. This consists of a rigid fiber board or cork cemented on the deck with hot asphalt or tar. The insulation may be bolted to the deck on steep slopes.

**Heat Insulation.** — It is desirable to insulate the roof or the ceiling of the top story of all buildings. This reduces the heat losses and the condensation of moisture on the ceilings. The various materials on the market may be divided into the following classes:

Rigid materials, such as fiber boards, and cork boards, which hold their shape, possess considerable strength and can be used as plaster bases or on wood, concrete, or steel roof decks under various roofing materials.

Mats or quilts consisting of fibrous materials matted together between sheets of heavy paper forming a quilt from $\frac{1}{2}$ in. to 1 in. in thickness which can be used between rafters or in other protected positions.

Cast materials which are mixed with water to form fluids which are poured into place and set, forming light, porous, solid materials which may, if necessary, be made strong enough to place on roof decks and under roof coverings.

Loose filling consisting of granular, fibrous, or flaky materials which possess no strength and can be used only in confined spans such as exist between joists above plastered ceilings.

Fiber boards are usually about $\frac{1}{2}$ in. thick and are furnished in various sizes. When used on concrete, gypsum or steel roof decks under some type of roof covering they are usually held in place by a bituminous

cement applied hot in which the board is bedded. One or more layers may be used, each layer being bedded in bituminous cement. Such boards are strong enough to stand the load which they will be called upon to carry in this position. Cork board is furnished in thicknesses varying from 1 to 6 in., the 2-in. thickness being quite common. It is used in the same manner as fiber board. Fiber boards and cork boards may be used as combined insulators and plaster bases.

One of the most common of the cast materials consists of plaster of paris to which powdered limestone and alum have been added. When water is applied to this mixture, carbon dioxide is released and forms a foam-like liquid which solidifies forming a very porous mass. If this is used as a filling material between ceiling joists or in stud walls it need have little strength but if used on roof decks under some roof covering a dense material is required. The dense material is not as effective for insulation as the more porous material. This type of material may be so placed as to provide the slight slope which may be desired for flat roofs, the roof deck itself being level.

Cinders are extensively used on flat reinforced-concrete roof decks for insulation and to provide the desired slope. A layer from 3 in. to 12 in. or more in thickness may be used. The cinders are thoroughly compacted and are then covered with a thin layer of cement mortar to form a base for built-up roofing. Expansion joints must be provided between this layer and the parapet walls and at intervals over the entire area to keep the cement layer from pushing the parapet walls out or from buckling due to expansion caused by the heat of the sun.

**Roof Drainage.** — Roofs may be made flat with no slope whatever; they may be provided with a slight slope of ½ in. or 1 in. to the foot, or they may have considerable slope. Many engineers and architects advocate the absolutely flat or *dead-level roofs* because of the simplicity of construction, maintaining that the water which may stand for short periods on a roof due to slight irregularities does not harm and may actually protect the roof from the effects of the sun. The types of roofing used on dead-level roofs is a built-up roofing consisting of coal tar pitch and tarred felt with a wearing surface of gravel or slag.

The slopes required for various types of roofing are discussed in Articles 57 to 63. The rainwater which falls on a roof may be allowed to run off and drip from projecting eaves but usually it is necessary or desirable to collect the water in *gutters* placed along the eaves of sloping roofs, the water in the gutters being carried off by vertical pipes called *downspouts, conductors*, or *leaders*. Flat roofs or other roofs which do not have projecting eaves are drained by means of downspouts or conductors placed at points where the water is carried by the slight slope provided in the

roof. The size of the gutters and conductors is determined by the contributing area and by the intensity of rainfall.

Several types of gutters for sloping roofs are shown in Fig. 134*e*. The *hanging gutter* is the simplest form but is not as attractive as the *crown-mold gutter* or the *wood gutter* which fit into the design of the cornice. The *standing gutter* is inconspicuous and easily constructed but the *concealed gutter* is quite expensive. Gutters are sometimes called *eaves-troughs.* Cornices which are enclosed so that the rafters do not show are called *box cornices* and those in which the rafters are exposed are called *open cornices.*

Conductors or downspouts should be provided with strainers at their upper ends, as shown in Fig. 134*h*, so that leaves, sticks, and other débris cannot clog them. *Conductor* or *leader heads* are used as shown in Fig. 134*f*.[1] It is desirable to run conductors down inside of a building rather than to place them on the outside walls as the heat of the building keeps them from freezing. They may be placed in chases in the outside walls, along columns, or in partitions. If they must be placed on the outside of outside walls it is desirable to keep them off of north walls if possible. Steam outlets are frequently provided in exposed conductors so that, by discharging steam into them, they can be kept from freezing. Cleanouts should be provided so that clogged conductors and the connecting drains can be easily cleaned. Exposed conductors are commonly made of copper and galvanized steel but cast-iron and steel pipe are used for concealed conductors or where appearance is not a factor.

Where a roof surface meets a vertical wall it is necessary to provide *flashing* to make the joint watertight. Flashing usually consists of strips of some sheet metal such as copper or galvanized iron which is made L-shaped so as to fit over the joint as shown in Fig. 134*g*, one leg of the L running up the wall and the other along the roof. Rainwater which is driven against the vertical face of the wall is kept from running down behind the vertical leg of the flashing by *counter-flashing* or *cap flashing*, also made in the form of an L. The L is inverted, the horizontal leg being built or fitted into a mortar joint and the vertical leg fitting over the flashing as shown in Fig. 134*g*. Built-up roofing is commonly flashed as shown in Fig. 134*g* without the use of sheet metal. To avoid the sharp corner between the wall and the roof, *cant strips* or *boards* or concrete cants are commonly used. *Flashing blocks* as shown in the figure are frequently used. The angle between the back side of a chimney, or other projection, and a sloping roof is usually protected with a *saddle* or *cricket* which consists of two sloping surfaces meeting in a horizontal ridge perpendicular to the chimney. The valleys on sloping

[1] Copper and Brass Research Association.

roofs are made watertight by sheet-metal strips bent to fit the two intersecting roof surfaces.

### ARTICLE 57. SHINGLES

**Wood Shingles.** — The best wood shingles are made of cypress, cedar, and redwood, but white and yellow pine, and spruce shingles are also used. Wood shingles are tapered, and furnished in lengths of from 16 to 24 in., and thicknesses of from $\frac{1}{3}$ to 1 in. at the butt, the widths in each size being furnished at random. Dimension shingles are of uniform widths and may be obtained 4, 5, or 6 in. wide.

Shakes are 36 in. long, 6 in. wide and $\frac{1}{4}$ in. thick. They are not tapered.

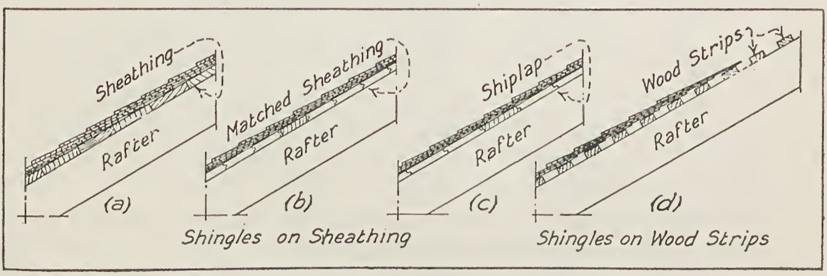


FIG. 135. Shingle Roofs

Wood shingles are furnished in bundles containing the equivalent of 250 shingles 4 in. wide, the standard of measurement being a shingle of that width. They may be obtained with or without preservative treatment or stain.

Wood shingles are nailed to wood sheathing or slats, each row of shingles being lapped over the row below to give an exposed surface, varying from 4 to 7 in., the smaller distance " to the weather" being used for short shingles on flat slopes, and the greater distance for long shingles on steep slopes.

The sheathing may have square edges as shown in Fig. 135*a*, it may be matched as shown in Fig. 135*b*; or it may be ship-lapped as shown in Fig. 135*c*. The use of wood slats is illustrated in Fig. 135*d*.

When the sheathing is without spaces between the boards, or when matched sheathing or ship-lap is used, a layer of waterproof paper may be placed between the sheathing, and the shingles. This paper makes the roof more air and watertight, but where there is heavy rainfall this paper may reduce the life of the shingles by making it impossible for them to dry out from the under side and thus cause rotting.

Shingle roofs should not be used with a flatter slope than 6 in. vertical

to 12 in. horizontal. The chief use of wood shingles is in residence construction. The following discussion of wood-shingle roofs is taken from the Report of the Building Code Committee of the Department of Commerce:

Probably no type of roof covering has caused more comment and discussion than the wooden shingle. The great danger of the wooden-shingle roof is from chimney sparks and flying brands from burning buildings or bonfires. The danger from chimney sparks is largely confined to wood or soft coal fires and the sparks resulting from the burning of chimney soot.

The wooden shingle has various well recognized merits. It is light in weight, has excellent insulating value, thus promoting comfort by equalizing temperatures, can be easily applied, furnishes attractive architectural effects, and high-grade shingles properly laid produce a roof of excellent durability.

The main objection to the use of wood-shingle roofs is the fire hazard. Sparks or flying embers are more likely to roll or blow off from the smooth surface of a newly shingled roof than from an old roof with weather-worn shingles having curled and broken edges. For this reason any treatment of shingles, such as staining or creosoting, which will tend to maintain a smooth surface incidentally improves their fire resistance. Few if any of the compounds used for treating shingles directly increase their fire resistance.

When wooden shingles are used the very best grades of shingles available should be obtained, as they are more economical to the house owner in the long run than the cheaper grades and prolong the life of a smooth surface roof, thus promoting safety. For best results use edge-grain shingles free from knots and other imperfections and having a thickness at the butt not less than that represented by five shingles in 2 in. (four-tenths inch each). Shingles are made in 16, 18, and 24 in. lengths. Sixteen-inch shingles on a roof having one-half pitch (6 in. in 12 in.) or greater should be laid $4\frac{1}{2}$ in. to the weather; 18- or 24-in. shingles can be laid safely with larger exposure.

Ordinary wire nails are entirely unsuited to hold shingles. They rust out long before the shingles decay. Hot-dipped, zinc-coated, cut iron nails are best. Plain cut or galvanized wire nails will serve fairly well. The heads of nails should not be driven into the shingles. Untreated shingles should be thoroughly wet before laying.

**Asphalt Shingles.** — Asphalt shingles are made of heavy felt saturated or coated with asphalt, and with crushed slate or other material embedded in an asphalt coating to form the exposed surface. The most common shape is rectangular, 8 in. wide and $12\frac{1}{2}$ in. long. As a rule, the shingles are of uniform thickness but some brands are tapered like wooden shingles. They are furnished as separate shingles or in strips 4 shingles wide. Various colors and patterns are available.

Asphalt shingles are nailed to tight wood sheathing with each row lapping over the row below leaving from 4 to 6 in. exposed to the weather.

They should not be used on slopes less than 6 in. vertical to 12 in. horizontal.

Asphalt shingles are quite durable but often suffer severely in heavy wind storms. They are relatively inexpensive and do not require painting.

**Asbestos Shingles.** — Asbestos shingles are made of asbestos fiber and portland cement under pressure. They are made in various colors and sizes with thicknesses varying from $\frac{1}{8}$ to $\frac{1}{4}$ in. and do not require painting. They are laid in the same manner as wood and asphalt shingles using zinc- or copper-coated nails, and should not be used on slopes less than 6 in. vertical to 12 in. horizontal. A roofers' felt should be used over the sheathing.

Asbestos shingles are much stiffer, more durable, more attractive, and more fireproof than asphalt shingles. They are much more expensive than wood or asphalt shingles and somewhat cheaper than clay tile.

**Metal Shingles.** — Metal shingles are made of sheet steel, galvanized or with a coating of tin, called tin-plate, or of tin and lead called terne-plate. They are also made of zinc or copper. Various patterns are available all of which are interlocking and are nailed to wood sheathing, covered with building paper, with nearly their entire surface exposed to the weather. Galvanized, tin-plate, and terne-plate shingles require painting but those of zinc and copper do not. Metal shingles are incombustible and will prevent fires caused by sparks and embers falling on the roof, but due to their high conductivity they do not afford as much protection to a frame roof structure, during severe exposure to fire, as some other roof coverings with lower conductivity. Terne-plate shingles are quite commonly used but tin-plate shingles are rarely used on account of their high cost.

A layer of roofers' felt $\frac{1}{16}$ in. thick placed between the shingles and the sheathing is quite effective in preventing quick ignition of the sheathing when the roof is exposed to burning brands or radiated heat. Asphalt-saturated felt papers should not be used under tin or terne shingles on account of destructive action of the asphalt on the tin.

Copper and not zinc-coated nails should be used with copper shingles and zinc-coated nails should be used with zinc shingles on account of the electrolytic action which may occur between zinc and other metals. This same precaution should be taken in selecting valleys, gutters, and other metal parts of a roof. In all cases where zinc is used in connection with another metal in exposed positions care must be taken to prevent actual contact between the two metals because of the danger of electrolytic action, with resulting corrosion of the zinc. Satisfactory insul-

ation can be secured by the use of portland cement, roofing cement, or asphaltum paint.

Due to their relatively low cost, their light weight, and their fair resistance to fire metal shingles are sometimes used instead of some of the more expensive roof coverings.

## ARTICLE 58. ROOFING TILE

**Clay Tile.** — Clay tile are made by shaping moist clay in molds and burning. Many different patterns are available, the most common being French or Ludowici, Spanish, English, and Mission or Pan Tile as shown in Fig. 136*a* to *d*. Shingle tile are rectangular slabs about ½ in. thick available in various widths up to 9 in. and lengths up to 14 in. Tiles of constant width are always used. They are laid in rows to break joints with the length exposed not more than one-half the length of the tile, minus one inch. The rows may be regular or irregular.

All forms of tile are nailed to wood sheathing, wood nailing strips, gypsum, porous terra cotta, or nailing concrete as shown in the figure. The nails should be preferably of copper but dipped galvanized steel nails are commonly used. Some forms of tile may be wired to closely spaced steel-angle sub-purlins but this practice is not common.

Special tile are available for the ridges, and hips of roofs. The valleys should be made with sheet copper but in some localities galvanized steel gives satisfactory service. One or two layers of roofers' felt should be placed under the tile to serve as a cushion, to keep air currents from lifting the tile from beneath, and to shed water while injuries or defects are being remedied.

The usual forms of clay roofing tile should not be used on slopes less than 6 in. vertical to 12 in. horizontal. A special form of tile called promenade tile is placed on a waterproof base to form the floor of roof gardens. They are rectangular and vary in size from 6 in. to 12 in. with a thickness of 1 in. The waterproof base is constructed in the same manner as a tar-and-gravel roof but the gravel is omitted and the tile are bedded on a layer of hot tar of roofing pitch.

Clay tiles are fireproof, durable, and attractive but they are expensive and on account of their weight require a strong supporting roof.

**Cement Tile.** — Cement tile similar to some forms of clay tile are on the market. They are made of portland cement and sand under pressure and are naturally cement-colored but they may be made of other colors by introducing the proper coloring material. The method of laying is the same as that described for clay tile.

Large interlocking reinforced-concrete tile covering an area of 2 ft. wide

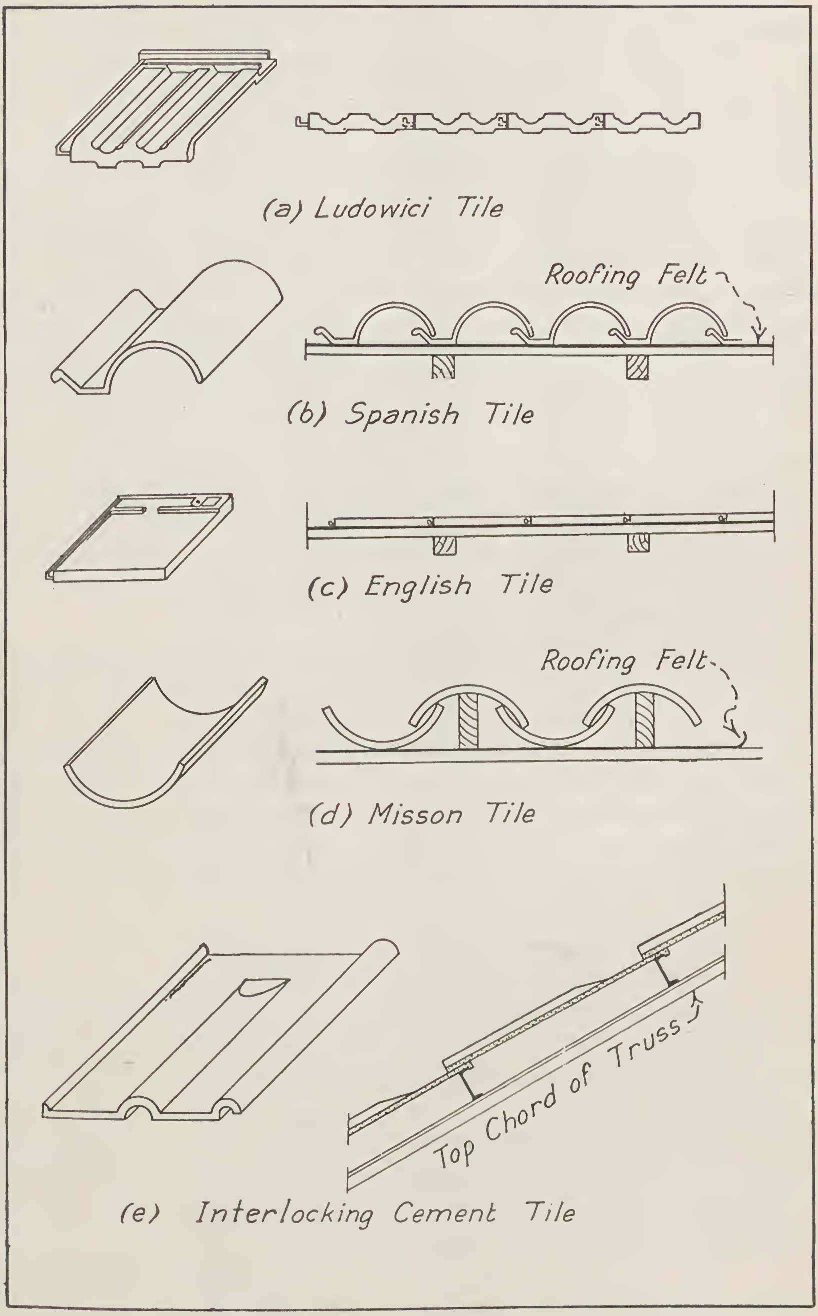


FIG. 136. Tile Roofs

by 4 ft. long, as shown in Fig. 136*e*, are on the market. These tile are laid directly on channel purlins properly spaced and are not fastened in any way. A projection at the upper end hooks over the purlin and keeps the tile from sliding down the slope. Special shapes are made for ridges, hips, and valleys. Large tile with wire-glass insets are available for use with the plain tile to serve as skylights.

Cement tile are fireproof and durable. They are cheaper but less attractive than clay tile. The large tiles are suitable for industrial buildings but on account of the absence of any form of sheathing they rapidly conduct heat and may permit condensation on the under surface.

**Metal Tile.** — Metal tile are made of sheet copper, zinc or steel pressed into shape to imitate clay tile. Steel tile may be obtained with terne plate or galvanized and are always painted. Metal tiles are nailed to wood sheathing covered with building paper or to nailing strips. See Article 88.

Copper or copper-coated nails should be used with copper tiles, zinc-coated nails with zinc and steel nails with steel tiles.

These tiles are fireproof and are less expensive and lighter in weight than the clay tile which they imitate but they are not as attractive in color or in texture.

Terne plate and galvanized steel tile require painting and it may be necessary to paint the copper and zinc tile to secure the desired effect but this is not necessary for protection.

In all cases where zinc is used in connection with another metal in exposed positions care must be taken to prevent actual contact between the two metals because of the danger of electrolytic action with the resultant corrosion of the zinc. Satisfactory insulation can be secured by the use of portland cement, roofing cement, or asphaltum paint.

## ARTICLE 59. SLATE ROOFING

Slate roofing is made from the natural rock by splitting and shaping into rectangular pieces of the desired dimensions. Slate for roofing should be hard and tough and should have a bright metallic luster when freshly split.

Slate is available in a great variety of colors such as gray, green, dark blue, purple, and red. It is furnished in about any size from 6 to 14 in. in width, 12 to 24 in. in length and $\frac{1}{8}$ to 2 in. in thickness, the common sizes being 12 by 16 in. and 14 by 20 in., $\frac{3}{16}$ and $\frac{1}{4}$ in. thick.

Roofs may be made of pieces of uniform size, thickness and color but random sizes, thicknesses and colors are also used.

Slate may be laid like shingles, each course lapping 3 in. over the second

course below or they may be laid at random, care being taken to give sufficient lap. They are nailed to wood sheathing or nailing strips, gypsum or porous terra cotta, holes being drilled in the slate at the factory. A layer of roofers' felt is used between the slate and the sheathing. The nails should preferably be copper, or yellow-metal slater's nails although redipped galvanized nails and copper-coated nails are commonly used.

Slates may be supported directly on steel sub-purlins to which they are wired. Slate roofs should not be used on slopes less than 6 in. vertical to 12 in. horizontal.

Slate may be used on flat roofs for roof gardens by omitting the gravel on the ordinary tar-and-gravel roof and bedding the slate in hot asphalt or roofing pitch.

Slate roofs are fireproof, durable, and attractive. All of the slate used in this country comes from quarries in Vermont, Pennsylvania and other eastern states, so the cost increases according to the distance from these sources of supply. Slate roofs may be classed as expensive

## ARTICLE 60. SHEET-METAL ROOFING

**Method of Laying.** — Sheet-metal roofing of tin plate, copper, zinc and lead is quite widely used. It may be laid with a *flat seam* as shown in Fig. 137*a* when the pitch of the roof is small or with a *standing seam* as shown in Fig. 137*b* on steeper pitches and running with the pitch of the roof. The seams are clinched tight, the separation shown in the figures being for the sake of clearness. Cross seams are always flat. Flat seams are soldered but standing seams are not. The sheet metal is fastened by means of metal cleats 8 in. to 12 in. apart which are locked into the seams, the cleats being nailed to the sheathing. Nails should not be driven through the sheets. Batten or ribbed roofs are formed by using wood battens or ribs running with the pitch of the roof. Sheet metal troughs are fitted between these battens and caps are placed over the battens as shown in Fig. 137*c*.

Sheet metal is placed over matched wood sheathing, a layer of roofing felt being used between the metal and the sheathing. An important function of this felt is to prevent quick ignition of the wooden decking when the roof is exposed to burning brands or radiated heat. It should be at least $\frac{1}{16}$ in. thick. Tar paper should not be used under tin roofs on account of the deleterious effect of the asphalt on the tin, but a rosin-sized paper is satisfactory.

In all cases where zinc is used in connection with another metal in exposed positions, care must be taken to prevent actual contact between

the metals because of the danger of electrolytic action, with the resulting corrosion of the zinc.

Satisfactory insulation can be secured by the use of portland cement, roofing cement or asphaltum paint.

**Tin and Terne Plate.** — Tin plates are made by dipping plates of sheet steel or iron in a molten bath of tin forming *bright tin plates* or a molten bath of tin and lead forming *terne plates.* When leaving the molten bath the plates are usually passed through rolls, the pressure on the rolls

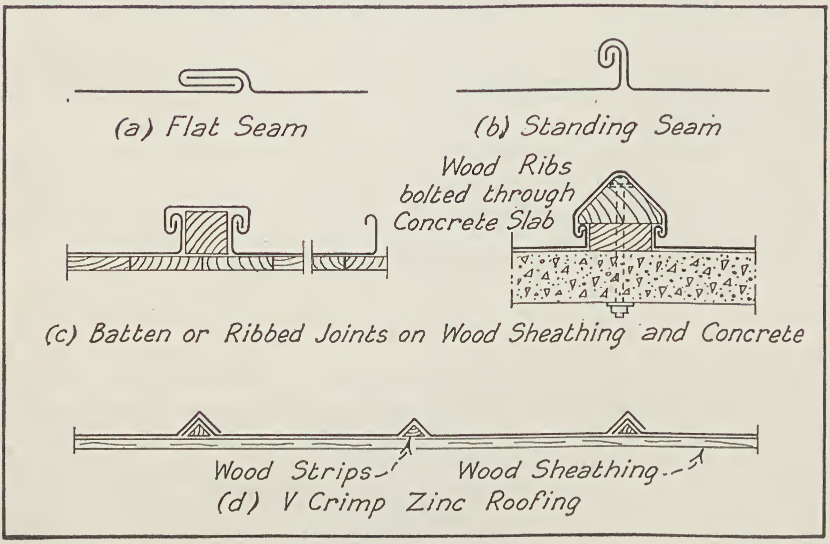


Fig. 137. Sheet Metal Roofs

determining the thickness of the plate. Bright tin plates are superior to terne plates but are so expensive that terne plates are usually used for roofing. The common sizes of sheets are 14 in. by 20 in. and 28 in. by 20 in. See Article 88.

Tin roofs will last for many years if good material is used and if kept properly painted with red or white lead, iron oxide, metallic brown, or Venetian red, with pure linseed oil. Graphite or tar paints should not be used. Tin roofing is light and incombustible.

The methods used in laying tin plate are given at the beginning of this article.

**Copper.** — Copper sheets make a very satisfactory roof covering which has a high initial cost but is very durable and requires no painting. Exposure to the weather causes green copper carbonate to form on the surface which protects the remainder of the metal.

**Zinc.** — Zinc sheets may be used to form a durable and satisfactory roof covering. Flat sheets may be used with flat or standing seams. Crimped sheets with longitudinal V-shaped crimps spaced 12 in. apart, are available. These sheets cover a width of 24 in. and laps are made at the crimps provided at the edges. V-shaped wood strips are placed 12 in. apart on wood sheathing or nailing strips and the crimps are placed over these strips as shown in Fig. 137*d*.

Exposure causes dull gray zinc carbonate to form on the surface which protects the remainder of the metal. Zinc does not require painting. It should not come in contact with other metals or it will be attacked by electrolysis when moisture is present. Zinc is more expensive than terne plate but cheaper than copper.

**Lead.** — Lead sheets are used for roofing to a limited extent. Lead is particularly suitable for curved or irregular surfaces for it can be easily stretched and worked to fit such surfaces without cutting. It has a large coefficient of expansion and is difficult to hold in place, particularly on pitched roofs.

A roofing known as "Hard Lead" is composed chiefly of lead but other materials have been added to increase the elastic limit and decrease the coefficient of expansion. This material has the advantages of ordinary sheet lead without the disadvantages. It may be used on any slope.

## ARTICLE 61. CORRUGATED STEEL, ASBESTOS PROTECTED METAL, ZINC, ASBESTOS BOARD AND GLASS

**Corrugated Steel.** — Corrugated steel is widely used for roofing on industrial buildings. The type commonly used has corrugations $2\frac{1}{2}$ in. wide and $\frac{5}{8}$ in. deep as shown in Fig. 138*a*, but other sized corrugations as shown in figure, are available. Corrugated sheets are 26 in. wide and may be obtained in lengths up to 10 ft. either painted or galvanized. See Article 88. The thicknesses in common use vary from 24 gage which is $\frac{1}{40}$ in. thick to 16 gage which is $\frac{1}{16}$ in. thick, the gage to be used in any case depending upon the spacing of the supports, the load to be carried and the quality of the building.

Corrugated steel may be nailed to wood sheathing or may be supported directly by wood or steel purlins spaced from 3 ft. to 5 ft. apart. The sheets are lapped $1\frac{1}{2}$ or 2 corrugations on the sides and 6 in. or 8 in. on the ends depending on the slope of the roof. On slopes as flat as 2 in. vertical to 12 in. horizontal standing seams similar to those described for flat sheet metal should be used instead of side laps.

Where steel purlins are used they may be provided with nailing strips to which the corrugated steel is fastened as shown in Fig. 138*b* or the

sheets may be held in place by straps passing around the purlins and riveted to the corrugated steel on each side of the purlin as shown in Fig. 138*c*. Long malleable nails called clinch nails may be driven through the

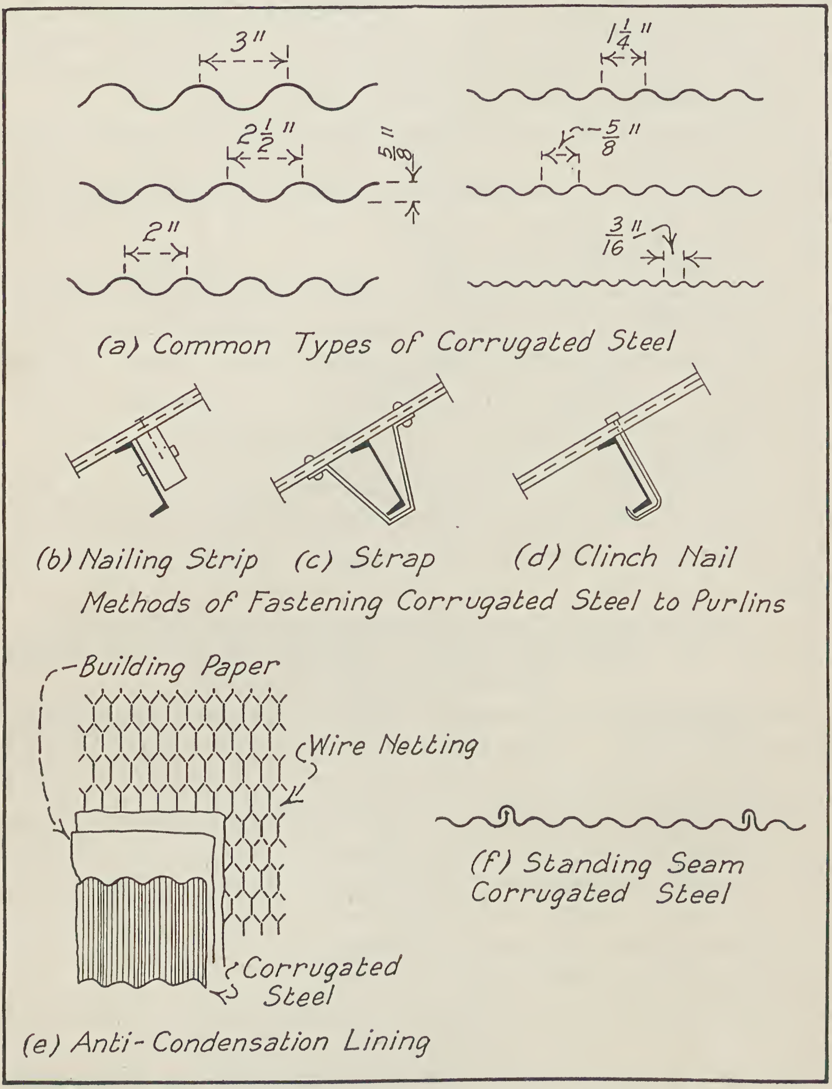


Fig. 138. Corrugated Steel Roofing Details

corrugated steel and clinched around the purlins as shown in Fig. 138*d*. The side laps are held together by copper or galvanized iron rivets spaced about a foot apart. All rivets and nails should be driven in the top of the corrugations to prevent leakage.

Since steel is a very good conductor of heat it is necessary to provide some form of lining for buildings where wood sheathing is not used and which are to be heated or in which the condensation of moisture on the under side of them is to be prevented. This anti-condensation lining usually consists of a layer of wire netting placed directly on the purlins and one or two layers of asbestos paper placed on the wire netting. The corrugated steel is placed over the lining as shown in Fig. 138*e*. The wire netting holds the asbestos paper in place and protects it.

When painted sheets are used they must be protected from corrosion by frequent painting.

Standing seam corrugated steel roofing is shown in Fig. 138*f*. This roofing is available in thicknesses from 16 to 28 gage, painted or galvanized. Cleats are used to fasten the sheets to wood or steel purlins. No rivets or nails are used and the sheets are not punctured in any way in placing. The use of this type of roofing is the same as ordinary corrugated steel.

**Asbestos Protected Metal.** — Asbestos protected metal consists of sheet steel covered first with a layer of asphalt, then a layer of asbestos, and finally a heavy waterproof coating. It may be obtained in flat sheets or corrugated sheets of the same size and shape as the plain corrugated sheets just described. The method of application is the same as for plain corrugated steel sheets but it does not require painting for it is well protected from corrosion and it is a poor conductor of heat and therefore may be used in places where the plain sheets are not suitable.

**Corrugated Zinc.** — Corrugated zinc sheets may be obtained with corrugations $1\frac{1}{4}$ in. or $2\frac{1}{2}$ in. wide. The width of sheets is usually about 2 ft. and lengths up to 10 ft. may be obtained. On sheets with corrugations $2\frac{1}{2}$ in. wide the corrugations are usually $\frac{5}{8}$ in. deep but special sheets with corrugations $\frac{7}{8}$ in. deep are available.

Corrugated zinc may be obtained in sheets of various thicknesses from $\frac{1}{50}$ to $\frac{1}{25}$ in. Corrugated zinc sheets are used in the same manner as that described for corrugated steel sheets. In fastening to wood sheathing or nailing strips, zinc-coated cut or wire nails should be used, and in fastening to steel purlins, zinc straps with tinned rivets and burrs, clinch nails with lead washers, or aluminum wire may be used.

Purlins may be spaced 5 ft. apart using sheets $\frac{1}{25}$ in. thick and with corrugations $2\frac{1}{2}$ in. wide and $\frac{5}{8}$ in. deep. The spacing may be increased to $6\frac{1}{2}$ ft. using sheets $\frac{1}{25}$ in. thick with $\frac{7}{8}$ in. corrugations.

Anti-condensation lining may be desirable with corrugated zinc and is applied in the same manner as that described for corrugated steel. Corrugated zinc roofing is much more durable than corrugated steel,

either plain or galvanized. The galvanized sheets depend upon the thin coating of zinc for protection from corrosion; naturally, the solid sheets of zinc are much more durable than the galvanized sheets. Zinc is not affected by sulphur fumes or smoke and does not require painting. Corrugated zinc is somewhat more expensive than galvanized steel.

**Corrugated Asbestos Board.** — Corrugated sheets made of asbestos fiber and portland cement are used in the same manner as corrugated steel. This material is a good non-conductor of heat and no trouble is experienced with condensation. It is durable and does not require painting.

**Corrugated Wire Glass.** — Corrugated wire glass sheets similar in shape to corrugated steel sheets are available for use alone or in connection with corrugated steel or zinc to assist in lighting the interior of buildings. These sheets are $\frac{1}{4}$ in. in thickness and have wire netting embedded in the glass to strengthen it and to hold it in place when a break occurs. The glass sheets are not laid with side laps but the joint is covered with metal caps held in place by bolts passing between the sheets. The sheets are held to steel purlins by clips bolted to the metal cap covering the joint between sheets. Strips of asphaltic felt are placed over the purlins to act as a cushion for the glass.

## ARTICLE 62. BUILT-UP AND PREPARED ROOFINGS

**Built-up Roofing.** — Built-up roofings consist of several layers of saturated felt cemented together with roofing cement. There are three types of saturated felts: asphalt asbestos-felt, asphalt rag-felt, and tar rag-felt. The roofing cements used are asphalt or tar pitch. Asphalt cement is used with the asphalt-saturated felts and tar pitch with the tar-saturated felts.

*Asphalts* may be defined as solid or semi-solid native bitumens obtained by refining petroleum, or solid or semi-solid bitumens which are combinations of the bitumens mentioned with petroleums or derivatives thereof, which melt upon the application of heat and which consist of a mixture of hydrocarbons and their derivatives of complex structure.[1]

*Tars* may be defined as bitumens which yield pitches upon fractional distillation and which are produced as distillates by the destructive distillation of bitumens, pyrobitumens, or organic materials. *Coal tar* is produced by the destructive distillation of coal. *Gas-house coal tar* is produced in gas-house retorts in the manufacture of illuminating gas from bituminous coal. *Coke-oven tar* is coal tar produced in by-product coke ovens in the manufacture of coke from bituminous coal.

[1] American Society for Testing Materials, Serial Designation D8–18.

*Water-gas tar* is produced by cracking oil vapors at high temperatures in the manufacture of carburetted water-gas.[1]

A built-up roof applied to a concrete deck is illustrated in Fig. 139, each layer lapping over the layers below and being cemented to it with roofing cement so that in no case will felt touch felt. The thickness of the roof is designated by the number of layers of felt at any point. A four-ply roof is four layers thick as shown in the figure.

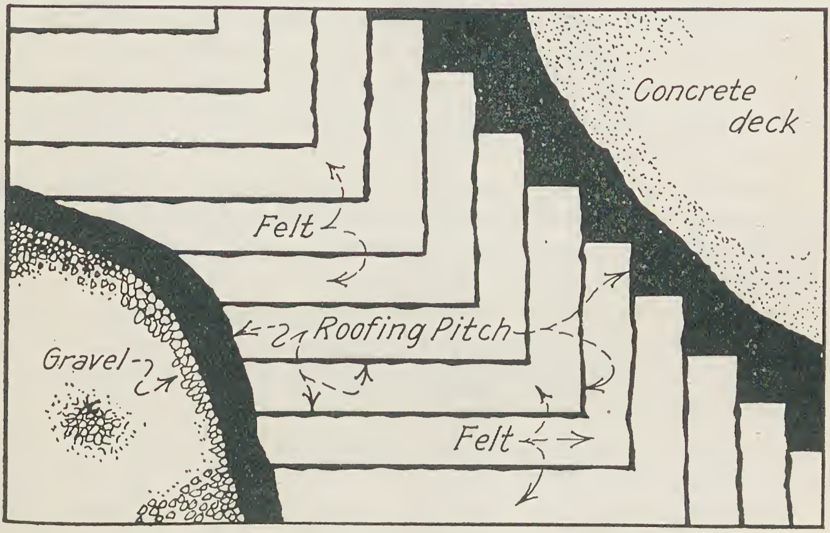


FIG. 139. Four-ply Built-up Roofing on Concrete Deck

The top surface of built-up roofing may be given a heavy coat of hot roofing cement. This may be left without further treatment but it usually has gravel or slag from $\frac{1}{4}$ in. to $\frac{5}{8}$ in. in size embedded in this coating to form a wearing surface. Tile, slate, and concrete wearing surfaces are commonly put over built-up roofs to form floors for roof gardens, etc.

Built-up roofs are usually used only on roofs with a very slight pitch such as one-half inch to the foot because the cementing material will flow in hot weather but by using special materials they may be applied to sloping roofs. The slag or gravel wearing surface is not used on sloping roofs.

A special form of built-up roof designed for very long life such as required on monumental structures consists of two or three plies of sheet lead laid in asphalt over a layer of felt cemented to concrete or gypsum decks with asphalt. If a wood deck is used the felt is nailed to the deck.

[1] American Society for Testing Materials.

After the lead has been placed the entire surface is rolled with roller and is then coated with hot asphalt. The lead sheet acts as a seal which prevents the evaporation of the volatile oils in the under layers of bituminous material and thereby increases the life of the roofing.

**Prepared Roofing.** — Prepared roofings consist of asbestos felt or rag felt saturated with asphalt and assembled with asphalt cement at the factory to form strips about 1 yd. wide and 12 yd. long. These roofings are equivalent to two-ply or three-ply built-up roofings. They may have a plain surface or may be surfaced with crushed slate, sand, mica or other mineral surfacing. Roofing of this type is furnished in rolls and is sometimes called *roll roofing.* It is ready for use and is sometimes called *ready roofing.* It is also known as *composition roofing.* Several grades differing in weight, durability, and fire-resistance are available.

Prepared roofing is nailed to wood sheathing using special nails with large heads, the edges of the roofing being lapped about 2 in. and cemented. The nails are placed in the laps. This type of roofing is cemented to concrete with roofing cement.

Prepared roofings may be used on any slope greater than 2 in. vertical to 12 in. horizontal. On the flatter slopes great care must be used to have the joints cemented tightly. They are inexpensive but have a relatively short life.

One form of prepared roofing has a cloth surface for use on roofs which are subject to foot traffic.

**Canvas Decking.** — Deck cloth is a canvas treated by a process which makes it waterproof and increases its wearing qualities. It is stretched tight, held in place with closely-spaced tacks, and painted with white lead and oil colored as desired.

Untreated canvas may be used for roof decking by bedding it in a coat of wet paint, lapping at least $1\frac{1}{2}$ in., and placing tacks at the edges and on the laps $\frac{1}{2}$ or $\frac{3}{4}$ in. apart.

These types of roofing are used on decks subject to foot traffic. They are relatively inexpensive but do not give the attractive and durable roof obtained with promenade tile.

## ARTICLE 63. COMPARISON AND USES OF ROOFING MATERIALS

**General.** — The factors which must be considered in selecting a roof covering are:

1. Slope of roof.
2. Durability.
3. Initial cost.
4. Maintenance cost.
5. Resistance to fire.
6. Weight.
7. Roof construction type.
8. Appearance.

The relative importance of these factors will vary with different classes of buildings. These factors have been considered to a certain extent in the previous articles but this article will serve as a summary.

**Slope of Roof.** — All forms of shingles, tile and slate require a slope of at least 6 in. vertical to 12 in. horizontal. Some forms of clay tile and slate flagging may be used to replace the gravel on flat tar-and-gravel roofs subjected to foot traffic. Corrugated sheets should not be used on a slope of less than 4 in. vertical to 12 in. horizontal. Sheet-metal roofs may be used on practically any slope, flat or steep. Prepared roofing may be used on any slope sufficient to provide drainage, if the joints are properly cemented. Built-up roofs may be used on any slope if the materials are properly selected, but their most extensive use is on flat roofs.

**Durability.** — The length of life of any roofing material depends upon so many factors which are variable that it is useless to attempt to give any more than comparative figures. The following classification will give an idea of the relative durability but should be considered only as a general indication of the durability.

1. *Long-lived:* Clay tile, slate, copper, zinc, and lead.
2. *Medium-lived:* Tin, asbestos protected metal, asbestos shingles, cement tile, built-up roofing.
3. *Short-lived:* Asphalt shingles, wood shingles, corrugated steel, prepared roofing.

Various destructive agencies must be considered in connection with durability. Clay tile and slate will break if walked upon, even if only while repairs are being made; slate and prepared roofings may suffer severely in hail storms — sheet steel, in any form, is particularly vulnerable to corrosive gases and salt air. Wind may have serious effects on roofs of tile, asphalt shingles, and prepared roofing. Tin, all forms of sheet steel, and wood shingles must be kept painted. If roofs are to be subjected to foot traffic a canvas decking may be used, or promenade tile or slate on a waterproof base.

**Initial Cost.** — The initial cost of roofing materials varies greatly from time to time and varies also with the locality. For instance, slate roofing comes from Vermont, Pennsylvania and other eastern states and is therefore more expensive in the West than in the East on account of freight charges. Wood shingles are cheaper on the Pacific coast than in most other localities. Clay tile are manufactured at many points throughout the country. The following classification will give an idea of the relative cost of roofing materials:

1. *Expensive:* Clay tile, slate, sheet copper, lead.
2. *Medium Priced:* Zinc, tin, asbestos protected metal, asbestos shingles, cement tile, metal shingles, metal tile.
3. *Low Priced:* Asphalt shingles, wood shingles, corrugated steel, built-up roofings.
4. *Cheap:* Prepared roofings.

Cheap prepared roofings may cost as little as 5 cents per sq. ft. whereas the more expensive forms of tile roofs may cost as much as 60 cents per square foot.

In determining the cost of a roof covering the indirect cost due to the effect of the weight on the cost of the supporting structure must be considered. In this respect various forms of shingles, sheet metal, and prepared roofings have advantage over tile and slate. The cost of preparation of the supporting structure to receive the roofing is also a factor to be considered.

**Cost of Maintenance.** — On certain classes of roofing materials there is a continual charge for maintenance in the form of painting; on others only the damage due to accident or unusual hail or wind storms need be considered; whereas on others there is practically no expenditure for maintenance. The following classification will give an idea of the relative cost of maintenance of various roofing materials:

1. *Frequent Painting or Repairs:* Wood shingles; corrugated steel; tin and galvanized iron sheets, tile, and shingles; prepared roofings.
2. *Occasional Repairs:* Clay tile, slate, cement tile, asphalt shingles, asbestos shingles.
3. *Very Little Maintenance:* Built-up roofing, copper, zinc and lead.

**Resistance to Fire.** — A very important factor in the selection of a roofing material is the resistance to fire. Many building codes will not permit wood shingles to be used except in very isolated locations. The actual resistance of the roof covering to fire is of more importance when the supporting structure is timber than when it is of fireproof construction. Sheet-metal roofing on roofers' felt, will protect wood sheathing from being ignited from sparks and will protect sufficiently against a moderate exposure to fire. Clay and cement tile, and slate are more effective than the materials just mentioned although slate will decompose at high temperatures. Built-up roofing, asbestos shingles and asphalt impregnated asbestos roof coverings will withstand quite severe fire exposures. See discussion on fire resistance under the heading of "Wood Shingles" in Article 57

**Weight.** — The effect of weight on the cost of the supporting structure has been mentioned. If one roofing material is to be replaced with another, the weight may often be a determining factor in the choice of material on account of the strength of the roof construction already in place. The lightest roofing materials are tin, copper, zinc, wood and asphalt shingles, and prepared roofings. Asbestos shingles, clay tile, cement tile, and slate roofs are quite heavy.

**Type of Construction.** — The methods used in fastening the various roofing materials to the supporting roof construction make it necessary to consider the character of this construction in selecting a roof covering; however, the type of construction of the supporting roof will usually have been adapted to the roof covering which has been selected.

Wood sheathing, gypsum, or porous clay tile may all be used to receive the nails which hold shingles, slate, tile, or sheet metal in place and are suitable for prepared roofing and built-up roofing which are to be cemented down with hot roofing pitch or similar material. If a roof is to be exposed to severe winds, nails driven in gypsum or porous clay tile may work loose, therefore it is desirable to use wires which pass through holes drilled or punched in the gypsum or supporting tile and which are fastened to the under side of these materials.

Concrete construction, in its various forms, is suitable for the application of coverings such as prepared roofing or built-up roofing which are to be cemented down with hot roofing pitch or similar material. Nailing concrete may be used for coverings which are to be held in place with nails. Nailing strips may be fastened to concrete to receive any form of roofing, but such strips are not usually necessary on wood, gypsum, or porous clay tile and where necessary they are more easily fastened to these materials than to concrete.

Where roof coverings are to be supported directly on the members of the structural frame without sheathing or other material to form a continuous surface it is necessary to use corrugated steel or zinc sheets, corrugated asbestos board, or large reinforced cement tile. In some cases closely-spaced sub-purlins may be provided to support ordinary tile or slate which is wired in place.

**Appearance.** — The kind of roof covering selected for a building will depend largely upon whether or not the roof may be seen. If the roof is flat a built-up roofing will be very suitable. If the roof is exposed to view, the roofing will be selected to harmonize with the remainder of the building, with attention to the factors which have been considered in the previous paragraphs. Wood shingles may be made very attractive and this type of roofing is extensively used on residences in spite of the fire risk and the cost of frequent painting. Asphalt shingles are replacing

wood shingles on account of the supposed smaller fire risk and the saving in painting, but they are not generally considered as attractive as wood shingles. Large cement tile are quite satisfactory in appearance for industrial buildings; and on such buildings where appearance is not an important factor prepared roofing or corrugated sheets of various materials may be used.

**Summary.** — In high-class buildings and residences with sloping roofs exposed to view, clay tile, slate, asbestos shingles and sheet copper may be considered the most suitable roofing materials.

On less expensive buildings with sloping roofs exposed to view asphalt or wood shingles, small cement tile, zinc or tin may be used. Metal tile may also be used on this class of structure but they are often objected to because they are merely imitation of real tile.

On the cheapest class of buildings, with sloping roofs, corrugated zinc or steel, or prepared roofing may be used.

On industrial buildings the question of appearance is of less importance than durability. On sloping roofs large reinforced-concrete tiles are very suitable or if a cheaper roof is desired, corrugated zinc or steel may be used with or without anti-condensation lining. Asbestos-protected metal is expensive but makes an excellent roof. Prepared roofing mopped on may be used.

For flat roofs, built-up roofing is probably the most satisfactory but prepared roofing mopped or nailed on may be used to lower the initial cost.

Roofs which are required to withstand foot traffic may be covered with cloth-covered prepared roofing, canvas decking or untreated canvas bedded in oil paint if a low-priced roofing is desired. If the use of a more expensive roof is warranted, clay tile or slate bedded on a waterproof base may be used. Asphalt mastic as described in Article 51 is also used.

## REFERENCE

Sweet's Architectural Catalogue, published by the F. W. Dodge Corporation, New York City, contains the advertisements of various roofing material manufacturers in convenient form for reference.

## CHAPTER XI

# DOORS AND DOOR FRAMES

### ARTICLE 64. DEFINITIONS AND GENERAL DISCUSSION

**Parts of Doors and Door Frames.** — The parts of a door are indicated in Fig. 140. The horizontal members are called the *rails,* the vertical members the *stiles,* and the areas included between the rails and the stiles are known as *panels.* The stiles of a door which is hung on one side and has a lock on the other are called the *hanging stile* or *hinge stile* and the *lock stile.* Intermediate stiles are called *muntins.* The rails at the top and bottom of a door are called the *top rail* and the *bottom rail.* The intermediate rail on a door having three rails is called the *lock rail* but if there are two or more intermediate rails they are called *cross rails.* A sash, called a *transom,* may be placed over a door. The member between the door and the transom is the *transom bar.* The vertical crack between doors set side by side in the same opening may be covered by an *astragal.* These designations apply to most types of doors but not to all. There are many types of doors in use but only the more common types will be considered here. Doors of standard or stock types may be used or special doors may be made to suit individual requirements.

The *frame* which surrounds the door and holds it in position is illustrated in Fig. 140. It consists of the side members which are called the *jambs,* the top member called the *head,* and the *casings.* Outside door frames are provided with *sills* and with *thresholds.* The threshold enables a door to be cut short enough to clear floor coverings on the inside and still not leave a large crack under the door. Thresholds are frequently used under inside doors, particularly where the flooring material changes at the door. *Stops* are provided for the door to close against and to cover the crack between the door and frame or the frame is *rebated* or *rabbeted* as shown. The depression cut in the frame to receive the door is called a *rebate* or *rabbet.* An excellent form of stop is the *plowed-in* stop which is set in a groove provided in the jamb as shown. A stop attached to the face of a jamb is said to be *planted.*

Door frames may be set in masonry walls at the time the walls are constructed, in which case they are anchored to the walls by metal anchors which are fastened to the frames and built into the walls. Wood blocks may be built into masonry walls to form an anchorage for frames which are set after the walls are built. Openings to receive door frames are provided

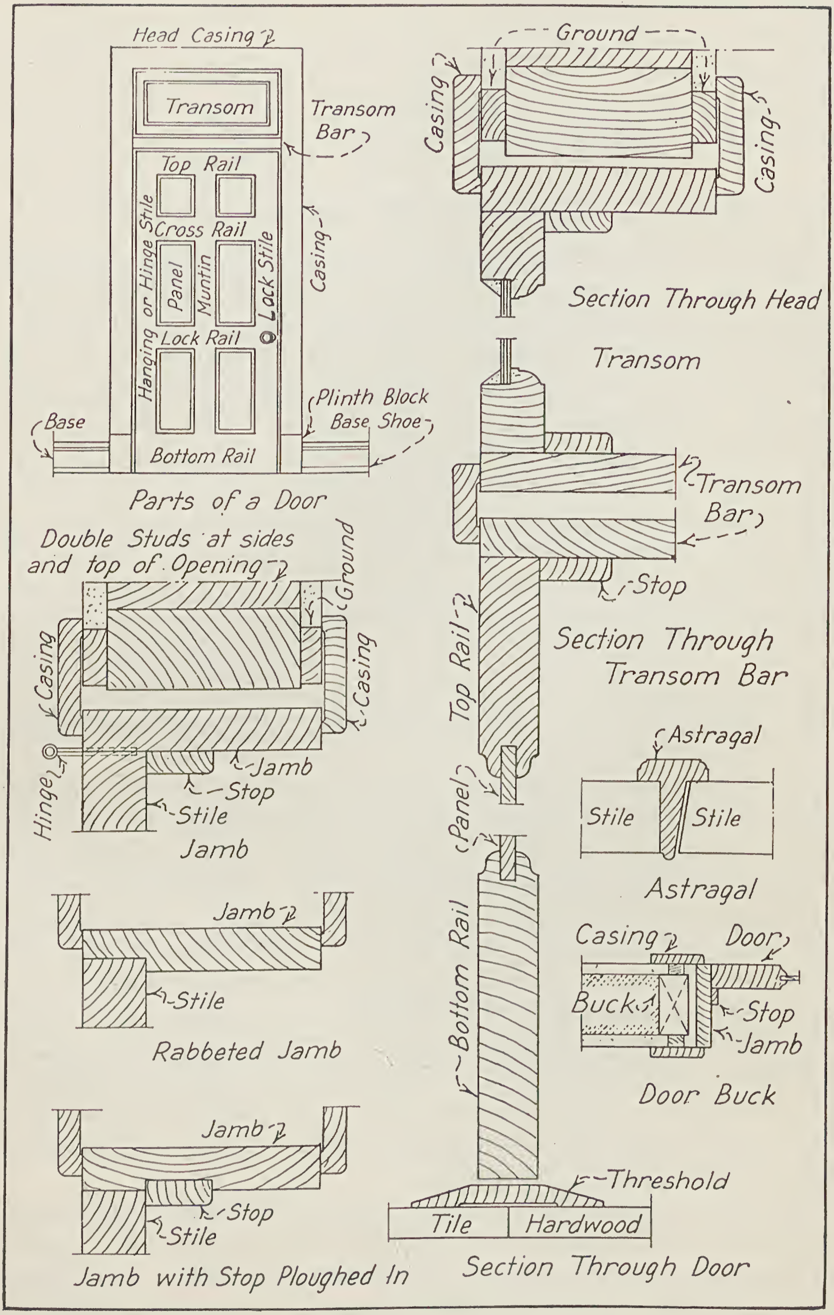


FIG. 140. Parts and Details of a Door

in walls and partitions with wood studs by doubling the members forming the jambs and the head. For wide openings, the head should be trussed as shown in Fig. 60*d*. Masonry partitions are provided with *door bucks*, which are rough frames as shown in Fig. 140 set at the time the partitions are built and anchored to the masonry by metal anchors. These bucks are constructed of wood for wood frames and doors and of steel channels or pressed steel for hollow metal doors. The openings provided are larger than the outside dimension of the frames to permit the frames to be plumbed.

**Operation of Doors.** — Doors are usually arranged to open by swinging about a vertical axis or by sliding horizontally but in some cases they may swing about a horizontal axis or slide vertically. These axes are provided by means of *hinges* or *butts* fastened to the door and the door frame. Horizontal sliding doors are suspended from *hangers* containing wheels which operate on tracks placed at the top of the door openings. Vertical sliding doors move between guides provided at the sides and are operated by cables or chains passing over pulleys in much the same way that double-hung windows are operated. They may be either counterweighted or counterbalanced as will be explained later.

The most common type of door is the swinging door shown in Fig. 141*a*. When ordering hardware for doors it is necessary to specify the *hand* and *bevel* of the doors. The hand of a door is determined by the side on which it is hinged. A door is beveled when the outer edge of the lock stile is not at right angles to the face of the door. Doors are beveled to keep them from binding on the jamb when opening and shutting. It is evident that the direction of the bevel is determined by the direction in which the door swings when opened. If one is standing on the outside of a door and the butts are at his left, the door is a *left-hand door*, but if they are at his right it is a *right-hand door*. If in opening the door it swings away from him, it requires what is called a *regular bevel* but if it swings towards him it requires a *reverse bevel*. In Fig. 141*a*, if the outside of the door is the side toward the lower edge of the page the door would be designated as left-hand, reverse bevel. The corridor side of interior doors is taken as the outside, as is the room side of closet doors. Many states require that all doors to buildings and rooms where many people congregate swing outward to avoid the possibility of the doors being blocked shut by crowds pushing against them in attempting to get out. Such doors are not permitted to have dead locks which require a key to open from the inside but should have locks operated by knobs or thumb turns from the inside or in the case of schools, theaters, auditoriums, etc., panic bolts, which release the lock when a crowd pushes against a door, should be used.

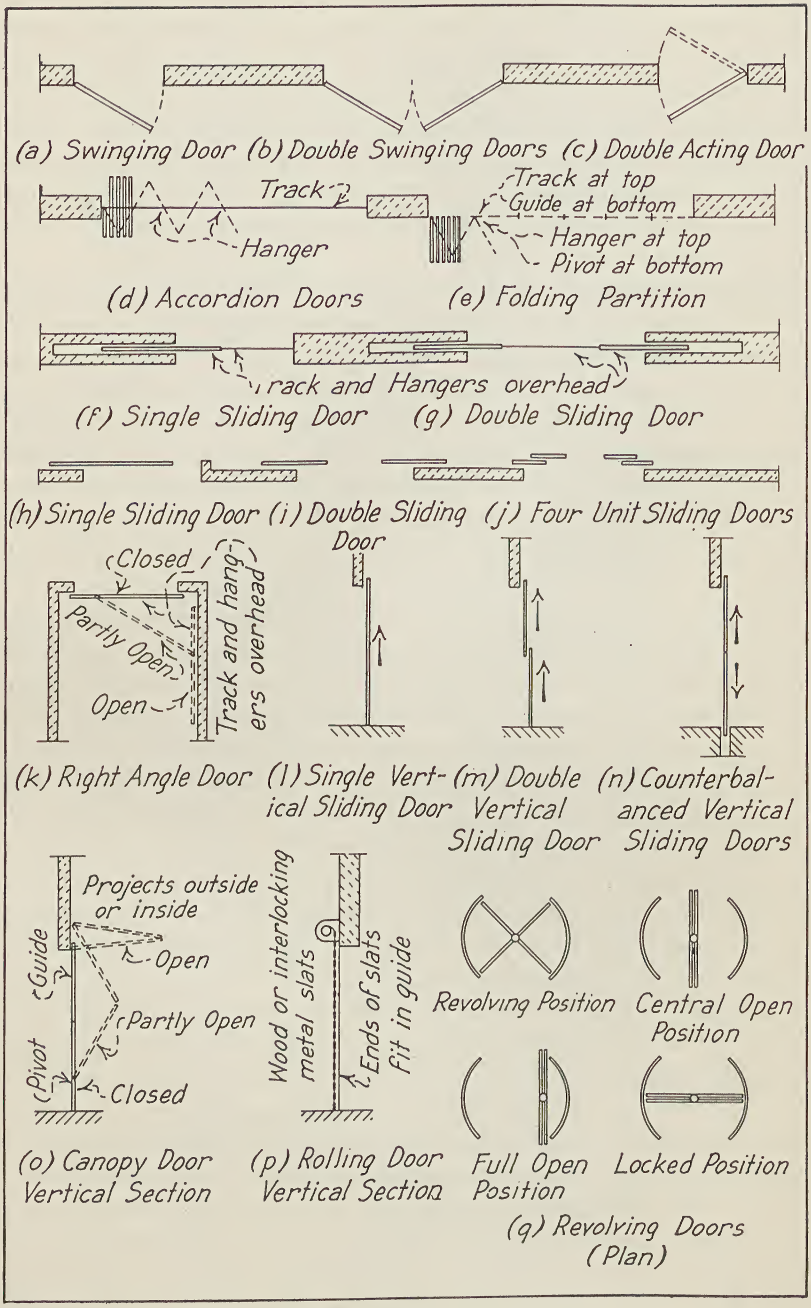


Fig. 141. Operation of Doors

Two doors hinged at opposite sides of an opening as shown in Fig. 141*b* are referred to as *double doors*. Such doors are extensively used at the entrances of buildings and of large rooms and even in the small rooms of residences to give a more spacious effect than would be secured with single doors.

The *double-acting door* shown in Fig. 141*c* is provided with special hinges which keep the door closed when it is not held open. The door can easily be pushed open in either direction and is convenient for use between a kitchen and dining room where those using the door may be carrying trays, etc.

The folding doors shown in Fig. 141*d* and *e* are used as folding partitions so that two rooms may be used together as a single room or separately. They may be made for very wide openings. Two or three doors hinged together as shown in Fig. 141*e* are commonly used for garages.

The sliding doors shown in Fig. 141*f* and *g* were quite extensively used in residences at one time but swinging French doors have largely taken their place. They slide into pockets provided in the partitions so are out of sight when not in use. The partitions must be about 12 in. thick to provide the pockets.

Doors sliding in one side of a wall or partition as shown in Fig. 141*h* and *i* are extensively used for fire doors which nominally stand open but which are released by a fusible link in case of fire. They may be made self-closing by sloping the tracks from which they are suspended or by properly arranged weights and pulleys.

Sliding doors as shown in Fig. 141*i* and *j* are commonly used for elevator doors. They are so arranged that they will all open when one is pulled back. The inner doors in Fig. 141*j* are arranged to move faster than the other two so that they will all be completely open at the same time. Two doors opening to the same side are more extensively used than the four-door unit shown.

The right-angle door shown in Fig. 141*k* is used to a limited extent on garages. The doors are suspended from an overhead track.

The vertical sliding doors in Fig. 141*l* and *m* are counterweighted and may be operated electrically. They are pulled up by cables or chains at each side of the opening that operate over pulleys in the same manner as for double-hung window sash. Such doors are used for large openings in industrial buildings, particularly for freight elevator doors.

Where conditions permit their use, the counterbalanced vertical sliding doors shown in Fig. 141*n* are very convenient. They are extensively used for freight elevator doors and can be easily operated by hand. When one moves up the other moves down an equal distance.

The canopy door shown in Fig. 141*o* is used for large openings in

industrial buildings. The door is counterweighted and may be electrically operated. If desired, it may open outward to form a canopy over the opening.

The rolling door shown in Fig. 141*p* operates in the same manner as a window shade. The roller on which the door rolls is operated by hand or electrically or by a spring which counterbalances the weight of the door. The door is made flexible by using wood slats or interlocking slats of sheet steel. The ends of the slats are held behind guides at the sides of the doors. Wood rolling doors are used to form movable partitions in the same manner as accordian doors and folding partitions shown in Fig. 141*d* and *e*. Steel rolling doors are very extensively used for large exterior doors of industrial buildings and for fire shutters which will close automatically in case of fire.

The revolving door shown in Fig. 141*q* is extensively used at the entrances of public buildings, banks, stores, etc. It does not permit cold air to come in from outside when it is in use. During mild or warm weather when it is not in use the revolving part may be moved out of the way as shown. The door may be locked when desired. Revolving doors are not included when figuring the exits required by building codes. In case of fire, the number of people they would accomodate in a short period of time is relatively small.

**Code Requirements.** — Building codes contain requirements concerning doors to insure the safety of the occupants of buildings. The following clauses taken from the Building Code of the National Board of Fire Underwriters may be taken as typical.

In every building except buildings of Class D, all required exit doors, including the doors of vestibules, shall open in the direction of travel. This requirement shall not prohibit the use of doors which swing both inwards and outwards, nor of sliding or rolling doors in stables, garages, storerooms, and the shipping and receiving rooms of manufacturing, mercantile and industrial buildings, where approved by the superintendent.

When exit doorways have a clear width of at least 40 in. each, the aggregate widths of such doorways shall be equal to the required width of corridor or stairway served by same. When individual doors are less than 40 in. wide, there shall be one doorway for each 22 in. of required width of corridor or stairway leading to the same. Every doorway shall be at least 28 in. wide in the clear. All passageway exit doors shall swing in the direction of exit travel, except in case of horizontal exits where direction of travel may be indeterminate.

All exit doors leading from rooms having an occupancy of 15 or over, shall open in the direction of exit travel, except in schools where fire drills are organized under control of the teachers.

The opening of one door shall not be permitted to obstruct another, and the arc of opening of doors which open upon stairway landings or platforms shall not

reduce the width of the passageway to less than the required width of the stairs.

Every room having an occupancy of more than 75 persons shall have at least two doorways remote from each other leading to exits.

At all times when any loft or space is occupied for manufacturing or mercantile purposes, the fastenings or locks on exit doors shall be such as may be easily opened from the inside without the use of keys.

Elevators, escalators and revolving doors shall not be considered in calculating exit requirements.

Building codes also contain clauses requiring fire doors in exterior walls which are exposed to fire hazards due to the nearness or to the non-fireproof construction of adjacent buildings. Fire doors are also required on the inside of buildings to check the spread of fires. Such clauses apply only to buildings within the fire limits. Fire doors must be so constructed as to resist a fire for one hour under standardized conditions. Various types of metal doors and metal-clad doors will give the required fire protection if properly constructed.

## ARTICLE 65. WOOD DOORS

**Material.** — Wood doors may be made of solid softwood such as white pine, cypress, redwood, and fir or they may be made of a hardwood *veneer* such as birch, oak, ash, gum, walnut and mahogany with a kiln-dried core of some softwood such as white pine.

Veneers are thin sheets of wood. They are made by three processes: the sawing process, the slicing process, and the rotary-cut process. In the *sawing process* the thin sheets of wood are cut from large blocks of wood by a circular saw. This process is wasteful because of the wood consumed in the saw-kerf but it produces the best grade of veneer because it injures the wood less than the other processes. In the *slicing process* the thin sheets are sliced off of the large blocks with a cutting knife. The wood is softened by steaming to make the cutting without splitting possible. In the *rotary-cut process* a log which has been softened by steaming or boiling is placed in a lathe and revolved against a wide stationary blade which gradually moves towards the center of the log and cuts off a continuous slice. The entire log can not be cut up in this manner but a core which must be discarded, so far as this use is concerned, remains.

The thickness of the veneer varies from $\frac{1}{16}$ to $\frac{1}{4}$ in.; the thicker veneers being used on the stiles and rails of exterior doors. The veneers on panels are sometimes as thin as one twenty-eighth of an inch. The veneer is fastened to the core with waterproof glue and is subjected to

pressure while the glue is drying. Veneered doors should not be used on the exterior of buildings unless they are protected from the weather. Doors may be obtained with solid stiles and rails and veneered panels.

**Types.** — Several types of doors are illustrated in Fig. 142.

The *ledged and braced door* shown in Fig. 142*a* is used only on cheap construction and may be made by the carpenters on the job. Its use is ordinarily confined to such buildings as private garages and stables but it is sometimes used in high-class construction where quaintness is desired. The horizontal members are called *ledges* and the diagonal member the *brace*. The brace prevents sagging. Three ledges and two braces are also used. The braces may be omitted if the ledges are securely screwed to the vertical boards. Doors may be constructed of vertical pieces 2 in. or more in thickness held together by horizontal bolts running from one edge of the door to the other and concealed in the thickness of the door. If the wood is well seasoned and the bolts are tight such doors may be very substantial. The heads of the bolts and the nuts are recessed in the edges of the door a sufficient depth so that they may be concealed by wood plugs.

The most common types of doors are *framed doors.* They consist of stiles, rails, and muntins, which are framed together, the enclosed areas being filled with panels. In some of these, glass panels are used instead of solid panels or a mirror may be placed on one side backed up with a solid panel on the other. Doors may have panels provided with slats or *louvres* for ventilating rooms. Doors in which the area included between the outer stiles and rails is divided by muntins supporting lights of glass are called *French doors.* Doors which are divided horizontally so that the upper part may be operated separately or the two parts may operate as a unit are called *Dutch doors.* Doors with plane faces are called *flush doors.* They are always of the veneered type. Flush doors may be obtained with inlaid borders or other inlaid designs. Flush doors are extensively used in hospitals for there is no place on them for dust to collect and they are easily cleaned. For this reason they are often called *sanitary doors.* Many types of doors not mentioned here are readily available, or doors may be built to special design.

**Construction.** — Several types of construction used on solid, and veneered doors are illustrated in Fig. 142*b*. The common thickness for standard doors are $1\frac{3}{8}$ in. and $1\frac{3}{4}$ in. the greater thickness being used for the larger doors and for exterior doors. The joints between stiles and rails may be of mortise-and-tenon construction or dowels may be used. The following suggestions for the preparation of door designs have been made by some door manufacturers:

The cores of veneered doors should be kiln-dried softwood.

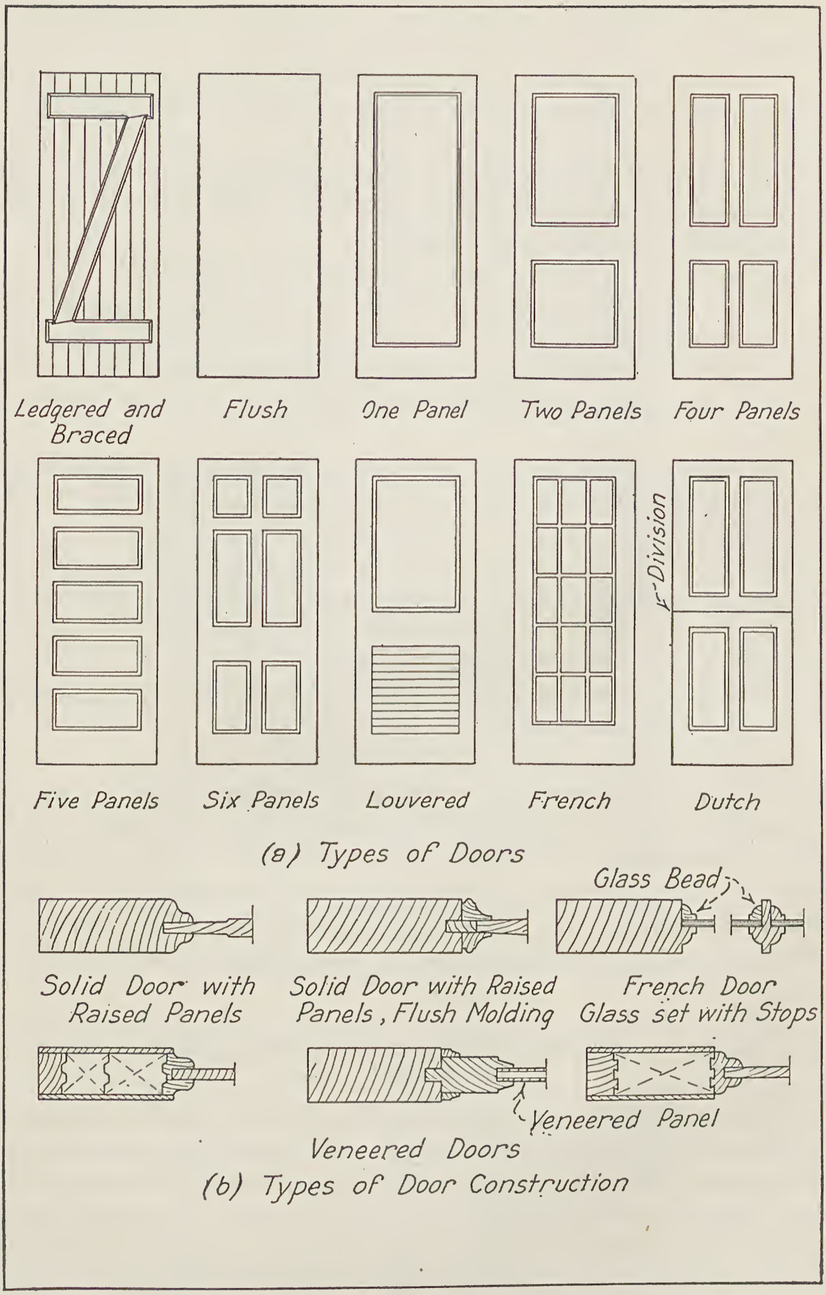


Fig. 142. Metal-covered and Hollow Metal Doors

Veneers for stiles and rails of exterior doors should be not less than $\frac{1}{4}$ in. thick.

One-panel doors should be not less than $1\frac{3}{4}$ in. thick.

Doors over 2 ft. 8 in. wide or 7 ft. high should be not less than $1\frac{3}{4}$ in. thick.

Doors veneered with two kinds of wood should be not less than $1\frac{3}{4}$ in. thick but they should be avoided if possible. For such doors, do not use rabbeted jambs or plowed-in stops.

Flush or sanitary doors should be not less than $1\frac{3}{4}$ in. thick.

The bars or muntins on French or sash doors should be preferably $\frac{1}{2}$ in. thick between glass.

The jambs and heads of door frames are commonly made from $\frac{7}{8}$ in. to $1\frac{3}{4}$ in. in thickness, the thicker material being required for rabbeted frames.

**Door Sizes.** — The standard sizes for stock doors vary with different manufacturers. The smallest door which is used to any extent is 2 ft. 6 in. wide by 6 ft. 6 in. high. This size of door is very common in residences but a 2 ft. 8 in. by 6 ft. 8 in. door is advantageous when moving furniture in and out. Office and schoolroom doors are commonly made 3 ft. 0 in. by 7 ft. 0 in. Doors wider than 3 ft. or higher than 7 ft. are not extensively used except as entrance doors or for special uses such as in hospitals where doors from 3 ft. 6 in. to 4 ft. 0 in. wide are used to provide clearance for hospital beds.

In general, doors may be obtained varying in width from 2 ft., by intervals of 2 in., to the width of 3 ft. and in height from 6 ft. 6 in., by intervals of 2 in., to the height of 7 ft. although doors 2 ft. 0 in. by 6 ft. 0 in. are available. All of these sizes may usually be obtained $1\frac{3}{8}$ in. thick and doors 2 ft. 6 in. or more in width may be obtained $1\frac{3}{4}$ in. thick. Doors thinner than $1\frac{3}{8}$ in. are used only on cupboards or for similar uses and doors thicker than $1\frac{3}{4}$ in. are rarely used except for special entrance doors.

## ARTICLE 66. HOLLOW METAL DOORS AND METAL-COVERED DOORS

Hollow metal doors are usually made of No. 18 gage furniture steel shaped as shown in Fig. 143*b* to form doors resembling wood doors in appearance. The top and bottom rails are commonly reinforced with steel channels concealed inside and reinforcement is provided where hinges, locks, door checks, etc., are to be attached. All seams and joints between stiles and rails are welded and so finished that they are invisible. Cork inserts are placed in the stiles and rails to prevent the metallic sound the door would otherwise make when jarred by closing. The

panels are lined with asbestos. The stiles and rails of the most fire-resistant types of doors are lined with asbestos. The finish on hollow metal doors is commonly baked enamel.

Hollow metal doors are provided with pressed steel frames and trim which are fastened to pressed steel bucks, steel channel bucks or wood bucks as shown in Fig. 143*d*, or the frame and buck may be combined as shown. Hollow metal doors are also made of No. 14 gage sheet bronze

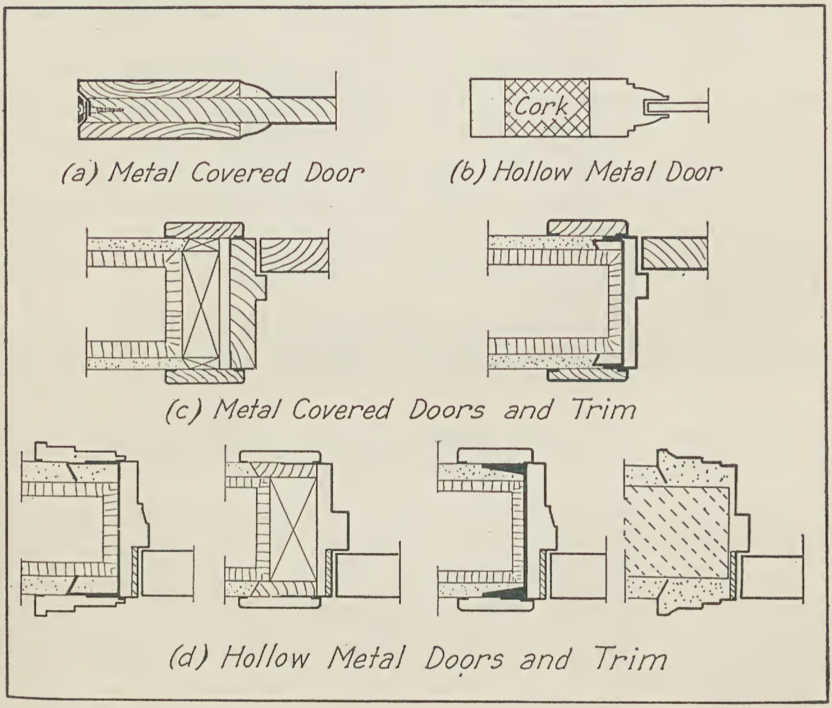


FIG. 143. Metal-covered and Hollow Metal Doors and Trim

and of extruded bronze members. Hollow metal doors may be used in preference to metal-covered doors and wood doors on account of their greater fire-resisting qualities and their freedom from shrinkage and swelling. They are more expensive than metal-covered doors and much more expensive than wood doors. They may be obtained in any desired style such as panel doors, flush doors, and French doors as shown in Fig. 142, but each manufacturer has standard types. The sizes correspond approximately to those of wood doors, a common thickness being $1\frac{3}{4}$ in., but elevator doors are made as thin as $1\frac{1}{4}$ in. and large doors as thick as $2\frac{1}{4}$ in.

Metal-covered doors consist of cores of thoroughly dried non-resinous

lumber such as white pine covered with a tight-fitting sheet-metal covering of furniture steel, galvanized steel, cold-rolled copper, sheet bronze, or kalamein metal which is steel with a thin coating of lead and tin and is called terne plate, as shown in Fig. 143*a*. The term kalamein is commonly applied to any metal-covered wood regardless of the metal used.

Wherever possible, the metal covering is tightly fitted to the core by drawing through dies. Panels are commonly made of asbestos or other fireproof composition board with metal glued on both sides under pressure with waterproof glue. Mortise-and-tenon joints are commonly used between the wood rails and stiles, and the metal joints are locked and soldered so that they are practically invisible and are tight so that moisture cannot penetrate into the door. Metal-covered frames and trim are available for use with metal-covered doors as shown in Fig. 143*c*.

Metal-covered doors are used where their moisture-proof or fire-resistant qualities are desired. They are not as fire-resistant as hollow-metal doors but are less expensive. They are considerably more expensive than wood doors.

The door sizes and styles for hollow metal and metal-covered doors correspond quite closely with those of wooden doors as shown in Fig. 142.

### ARTICLE 67. TIN-CLAD, SHEET-STEEL, CORRUGATED-STEEL AND ROLLING DOORS

Fire-resistant doors of various designs are on the market for use where hollow metal doors or metal-covered doors are too expensive and out of keeping with the use to which they are put. They are used in factories, warehouses, garages, etc., where appearance is not a factor. The most common types are the tin-clad door, the steel-plate door, and the corrugated-steel door.

Building codes require that doors in fire walls and other critical locations be so constructed as to provide a specified degree of fire resistance. Such doors are required to be self-closing or to be provided with automatic closers which will operate under the action of heat and cause the doors to close.

**Tin-clad Doors.** — Tin-clad doors consist of a wood core covered with terne plate. The cores are made of either 2 or 3 layers of 1-in. boards preferably tongued and grooved and not over 8 in. wide. If two layers are used, one is vertical and the other horizontal. If three layers are used the outer layers are vertical and the inner layer horizontal. The layers are securely fastened together by clinched nails or in some other manner in such a way as to give smooth surfaces. The covering of terne plate is made up of 14 by 20 in. sheets, preferably with double lock joints.

Solder, if used, must serve only to improve the appearance. The terne plate is held flat against the core by nails.

The three-ply doors are required where the most effective resistance is desired and the two-ply where only a moderate degree of protection is necessary.

Tin-clad doors are commonly surrounded with heavy angle frames to which they are bolted.

**Steel-plate Doors.** — Steel-plate doors consist of steel plates fastened to one side of an angle-iron frame or both sides of a channel frame, the frames being braced by intermediate members.

**Corrugated-steel Doors.** — This type of door is constructed of heavy corrugated steel sheets supported by a structural steel frame. The better class of doors consist of two thicknesses of corrugated sheets, one being placed with corrugations vertical and the other with corrugations horizontal, with an asbestos lining between the sheets. This lining is from $\frac{1}{8}$ in. to 1 in. in thickness. In some cases the structural steel frame is covered with a $\frac{1}{8}$-in. layer of asbestos. A cheaper and less fire-resistant door is made of one thickness of corrugated steel, with corrugations vertical, riveted to an angle-iron frame, intermediate braces being provided where necessary.

**Steel Rolling Doors.** — This type of door consists of a curtain of interlocking corrugated steel slats which rolls up on a roller or drum in much the same way as a window shade. See Fig. 141*p*. The edges of the curtain operate in vertical guides and the roller is housed in a steel hood. The curtain may be counterbalanced by springs so that it can be easily raised or lowered by hand, it may be operated by an endless chain with sprocket and gear, by a crank, or it may be operated by electric motor. Devices for closing the door automatically, in case of fire, are available.



## REFERENCE

Sweet's Architectural Catalogue, published by the F. W. Dodge Corporation, New York City, contains the advertisements of various door manufacturers in convenient form for reference.

# CHAPTER XII

# WINDOWS

## ARTICLE 68. DEFINITIONS AND GENERAL DISCUSSION

**Parts of a Window.** — The parts of windows of various types are indicated in Figs. 144 to 147. The two principal parts are the frame and the sash. The *frame* is the outer part of the window which is solidly fixed to, or built into, the wall and supports the *sash* which carry the glass and which may be fixed in position or may be arranged to open. The frame consists of four principal parts: the two vertical side members called the *jambs,* the horizontal member at the bottom called the *sill,* and the horizontal member at the top called the *head.* There may be one or more sash in a frame arranged in various ways as described later in this article.

Frames may be subdivided by vertical members called *mullions.* A sash is usually rectangular and consists of two side members called *stiles,* a top member called the *top rail,* and a bottom member called the *bottom rail.* A sash may carry one *light* or *pane* of glass or may be subdivided by means of vertical and horizontal members, called *muntins,* to carry several lights of glass. In *leaded glass windows* the glass is subdivided by lead strips which may be arranged to form rectangles, figures, or patterns. Windows of Gothic buildings are often ornamented by dividing the glass by means of bars of stone forming *tracery.* Wood is commonly substituted for stone to reduce the cost. A sash is held in its frame by means of *stops* which form ridges around the inside of the frame on each side of the sash. Glass is held in position by means of putty or *glass beads.*

If two sash are set one above the other in a frame and so arranged as to slide past each other, the top rail of the lower sash and the bottom rail of the upper sash are arranged to overlap and are called *meeting rails* or *check rails.* If sash are arranged to swing by hinging them to the stile on one side, the stile to which the hinges are fastened is called the *hanging stile.* If such sash are placed in pairs in a frame the stiles which are adjacent in the center of the frame are called *meeting stiles.*

**Types of Windows.** — Windows may be divided into several types depending upon the provision made for operating the sash. If sash do not operate they are called *fixed sash.* See Fig. 144*a*. Sash which are hinged on one side are called *casements.* If they swing outward, as shown in Fig. 144*b*, they are called *out-swinging casements* and if they

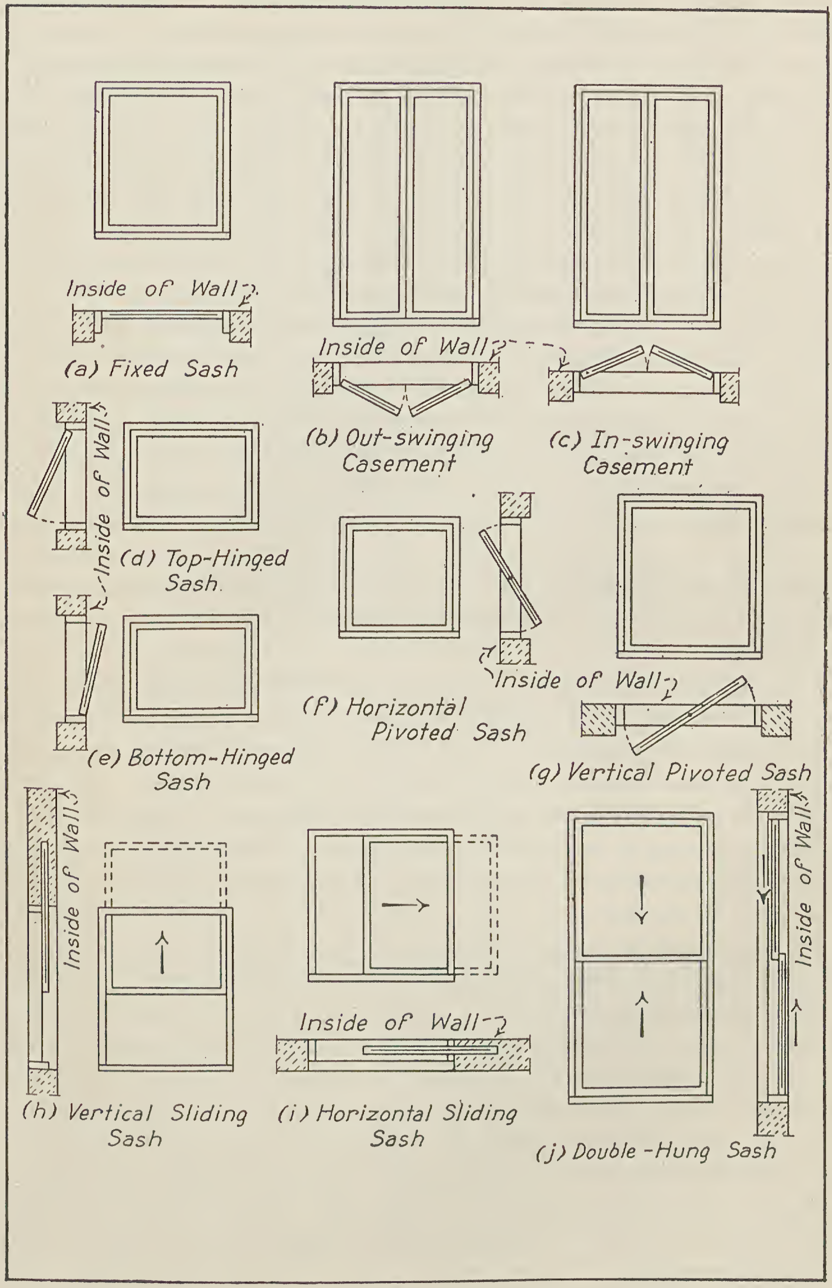


FIG. 144. Operation of Windows

swing inward, as shown in Fig. 144*c*, they are called *in-swinging casements.* Sash may be hinged at the top and swing outward or inward, as shown in Fig. 144*d*, or may be hinged at the bottom and swing inward, as shown in Fig. 144*e*. They may be pivoted at the centers of the stiles and rotate about a horizontal axis, as shown in Fig. 144*f*, or they may be pivoted at the center of the top and bottom rails and rotate about a vertical axis, as shown in Fig. 144*g*. A single sash may slide vertically, as shown in Fig. 144*h*, or horizontally, as shown in Fig. 144*i*. If two sash are placed in a frame and are so arranged that they can operate by sliding vertically by each other as shown in Fig. 144*j* they are said to be *double-hung.* In order to keep the rainwater which drains down over the upper sash from running in behind the lower sash the upper sash is always set outside of the lower sash. Windows with double-hung sash which are connected together by sash cords or chains passing over pulleys in such a way that one automatically lowers when the other is raised are called *counterbalanced windows*, the weight of one sash balancing the weight of the other. If each sash is balanced independently by weights operating in the weight box, the sash are said to be *counterweighted.* Other types of sash have been brought on the market by the manufacturers of metal sash. These will be considered later under the heading of metal sash.

The most common type of window is that with double-hung sash with counterweights or sash weights and, excepting factory sash, the next in popularity is the casement. The double-hung window is a very satisfactory type of window and one easily made weathertight. The chief objection to double-hung windows is that they permit only half of the window opening to be opened for ventilation. Out-swinging casements require the screen to be on the inside and are somewhat inconvenient to operate but the full area of the window may be opened. In-swinging casements must be carefully designed to keep rainwater from leaking in around the lower edge of the sash, they interfere with window drapes and with shades when opened and since they swing into the rooms they may be in the way. For these reasons they are considered by many an unsatisfactory type of sash. However, a properly designed sash will not leak and shades and curtains may be fastened to the sash themselves, thereby partially overcoming the objections to this type of sash. It provides the full area for ventilation. Casement sash are usually arranged in pairs, two narrow sash being used instead of one wide sash. Long casement windows reaching nearly to the floor are sometimes called *French windows.*

**Materials for Windows.** — Window sash and frames are made of wood and of metal. The kinds of wood selected for the various parts of

a window should be suitable for the service they are to perform. The sash have to withstand severe exposure and hard usage and they must not warp out of shape or shrink. Some of the kinds of wood which have been found to render satisfactory service for sash and other exposed parts are white pine, sugar pine, redwood, cedar, and Douglas fir. The pulley stiles over which the sash of double-hung windows slide are subject to considerable wear, so it is desirable to make these members of hard pine or some hardwood. The parts of a window which are not exposed are made of almost any kind of lumber available at low cost.

Metal windows are divided into three general classes; rolled or solid metal, hollow metal, and metal-covered windows. Metal windows are made of copper-bearing or non-copper bearing steel, galvanized steel, nickel silver, cold-rolled copper, and bronze. Metal-covered windows consist of a core of non-resinous wood such as white pine over which is tightly fitted a sheet-metal covering of one of the following materials: Terne plate, galvanized iron, cold-rolled copper, or sheet bronze.

The leakage of air through windows may be reduced by means of *weatherstripping.*

**Size of Windows.** — The Revised Code of Lighting School Buildings prepared by the Illuminating Engineering Society recommends that rooms be so designed that no work space is distant from the window farther than twice the height of the top of the window from the floor, and states that tests of daylight in well-lighted school buildings indicate that, in general, the window glass area does not fall below 20 per cent of the floor area. As the upper part of the window is more effective in lighting the interior than the lower part, this code recommends that the top of the glass be not more than 12 in. below the ceiling.

The following requirements for window area are given in Ketchum's Steel Mill Buildings:

Where buildings are lighted by windows having the sills not more than 4 ft. above the floor, the span of the building shall not exceed 2 times the height of the top of the windows where buildings are lighted by windows in one side, or 4 times the height of the top of the windows where buildings are lighted by windows in both sides. Where the span of the building is greater than is permitted by the preceding requirement, the necessary illumination shall be provided either by prism glass in side walls or by skylights. Skylights shall have such an area and shall be so arranged that light coming through the skylight making an angle of not more than 45° with the vertical shall cover the entire horizontal area at a distance of 6 ft. above the floor; or the light may be diffused by means of ribbed glass or prisms or by reflection from the ceiling to obtain equally satisfactory illumination. In saw-tooth roofs the inner surface of the roof shall be light-colored or shall be painted with a paint that will reflect the light and make the

illumination uniform and effective. All windows or skylights admitting direct sunlight shall be provided with muslin or other satisfactory shades.

Building codes commonly require rooms for human occupancy to have a window or skylight area of from one-eighth to one-tenth the floor area, at least one-half of which is arranged to open for ventilation. Properly designed artificial lighting and mechanical ventilation may be used instead of windows and skylights.

**Shutters and Storm Sash.** — Windows may be protected by shutters hinged to the sides of the opening on the outside. These may be of wood but if they are to protect a building from outside fires they are of steel. Building codes require steel shutters for severe exposures within the fire limits. Wood shutters are often used for decorative purposes in which case they are always left open and in some cases they are false shutters with no provision for closing. They are sometimes provided with louvres so as to obscure the view from the outside or shut out the light when closed but still permit ventilation. Inside shutters were used for this purpose many years ago but have gone out of use.

During the winter months screens are commonly replaced with storm sash in the colder climates to reduce the heat losses through windows.

**Fire Windows.** — Windows which are likely to be exposed to exterior fires are commonly required to be of fire-resistant construction if located within the fire limit districts. Such windows are called *fire-windows* and are required to withstand a fire for a period of one hour under standardized conditions. The size of a single pane or light is limited to 720 sq. in. with a vertical dimension not exceeding 54 in. and a horizontal dimension not exceeding 48 in. The glass used in fire windows is wired glass at least $\frac{1}{4}$ in. thick containing a layer of wire fabric reinforcement having a mesh not larger than $\frac{7}{8}$ in. and a size of wire not smaller than No. 24 B and S Gage. Hollow metal windows and windows with solid steel sections are satisfactory for fire windows when properly constructed for that purpose.

The National Board of Fire Underwriters maintains the Underwriters' Laboratories for the purpose of testing the fire-resisting properties of building materials and appliances.

## ARTICLE 69. WOOD WINDOWS

The common types of wood windows are the double-hung and the casement. Wood frames and sash are constructed in a great variety of ways, so the details given in this article only illustrate the general type of construction.

The thickness of sash for all types of windows is commonly $1\frac{3}{8}$ in. or

$1\frac{3}{4}$ in. The thicker sash are somewhat more expensive but should always be used in the better classes of buildings on account of their greater strength and rigidity.

A double-hung counterweighted window designed to be placed in a masonry wall is illustrated in Fig. 145. It consists of the following principal parts: the frame, the sash, and the interior trim. The principal parts of the frame, i.e., the head, jambs, and sill, and the parts of a sash are defined in Article 68. The following additional parts of a window are shown in Fig. 145:

*Weight box.* — The box provided to house the weights.

*Pulley stile.* — The part of the weight box next to the sash and against which the sash slide.

*Back lining.* — The part of the weight box next to the masonry.

*Box casing.* — The side of the weighted box.

*Parting strip.* — The guide between the two sash.

*Stop* or *stop bead.* — The outer and inner guides for sash.

*Pendulum.* — A thin partition of wood or sheet metal in the weight box to keep the weights from interfering with each other. This is fastened at the top only, so that it can be pushed aside to reach both sides of the weight box for repairs, through the pocket. This is also called a *parting strip.*

*Pocket.* — The removable section of the pulley stile to give access to the interior weight box.

*Yoke.* — The top member of the frame.

*Sill.* — The bottom member of the frame.

*Stool.* — The sill of interior finish.

*Apron.* — The part of finish below stool.

*Casing.* — The interior trim at sides of opening.

*Head casing.* — The interior trim at top of opening.

*Grounds.* — The strips under interior trim arranged to serve as guides to fix thickness of plaster and as nailing strips for interior finish.

*Brick mold.* — The mold in outside corner between frame and brick work.

*Staff bead.* — The general term for brick mold to apply to other materials.

*Reveal.* — The exposed masonry on jamb between frame and outside face of wall.

*Jamb casing.* — The interior trim on jambs of opening where frame is so set as to give a reveal on inside of opening.

*Pulley.* — A pulley is set in pulley stile to receive the sash cord which connects the sash and the counterweight or sash weight.

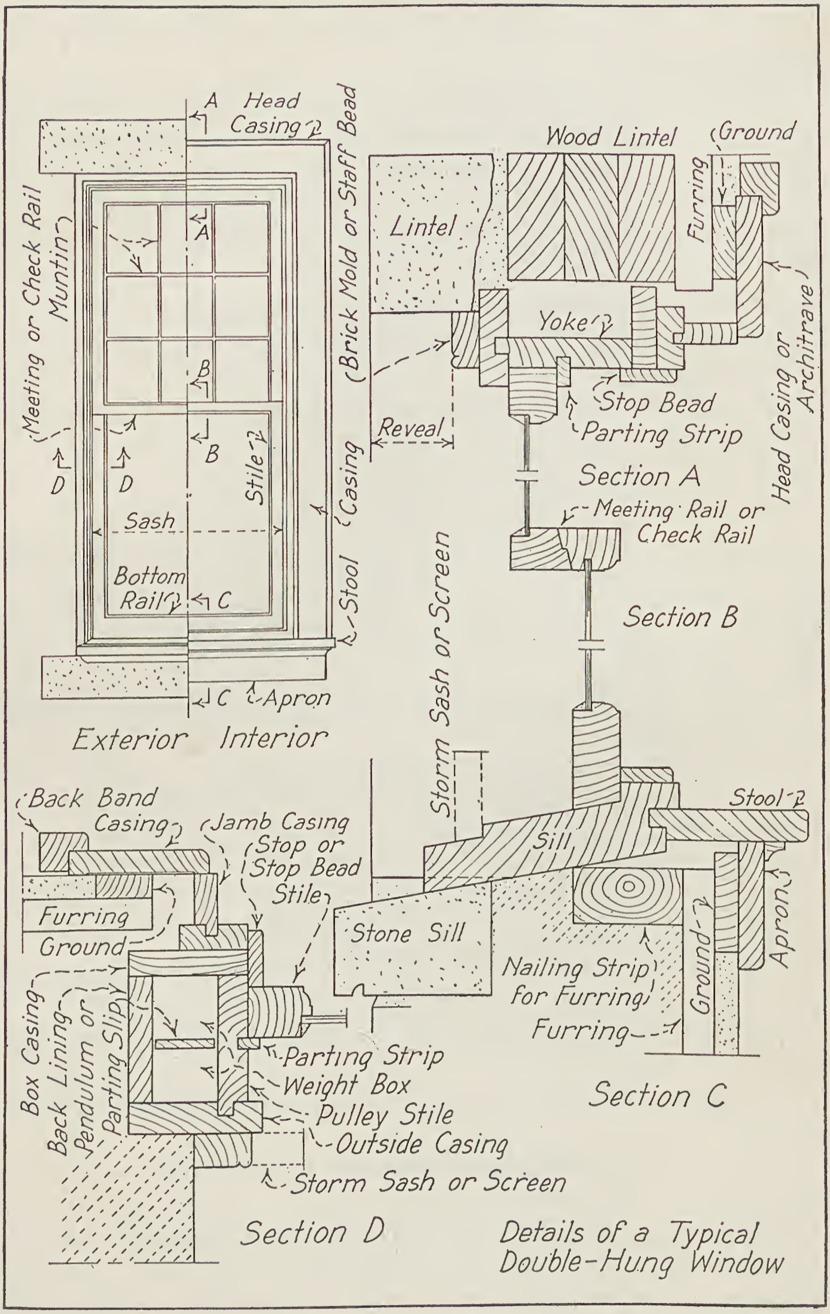


FIG. 145. Details of Double-hung Windows

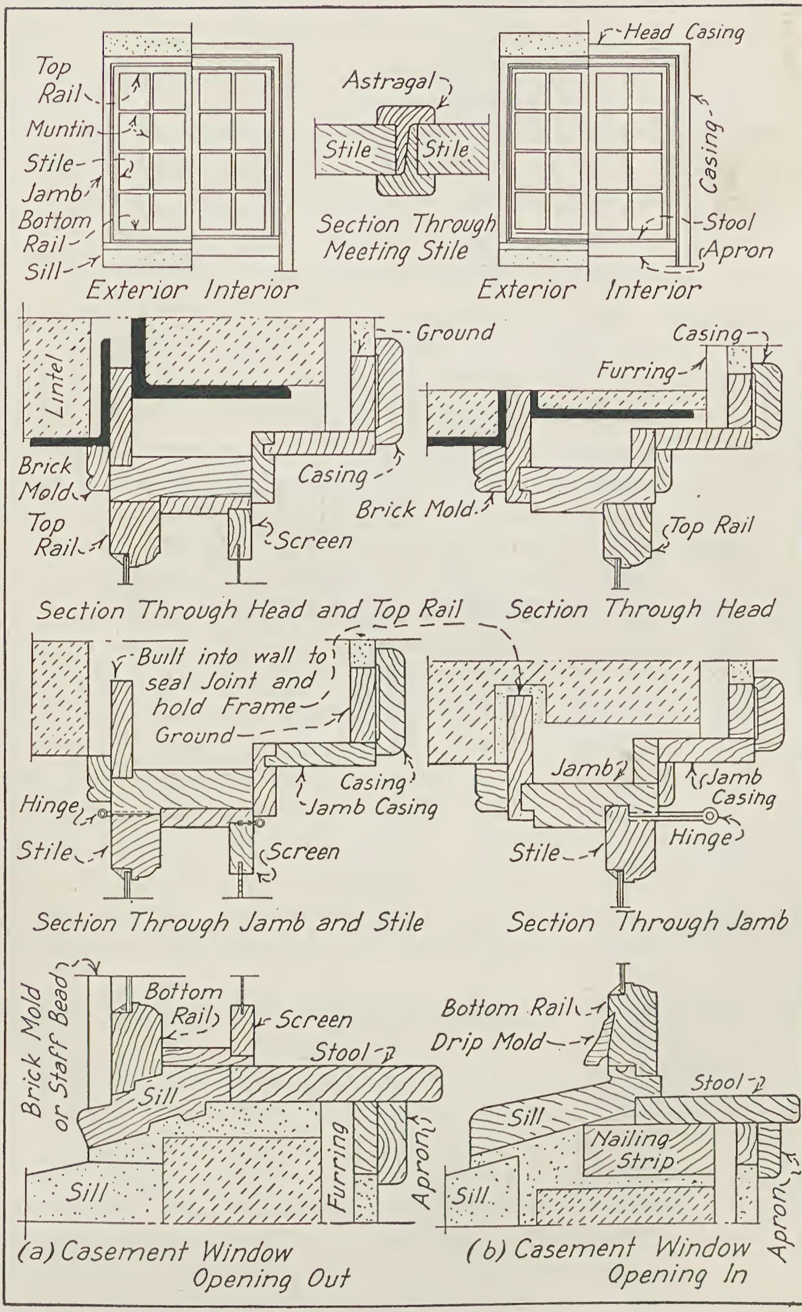


FIG. 146. Details of Casement Windows

An out-swinging casement window for a masonry wall is illustrated in Fig. 146*a*, and an in-swinging casement window in Fig. 146*b*. They consist of the following principal parts: Frame, sash, and trim. Casement windows commonly have two sash. The width of a sash should not exceed 2 ft. 6 in. and its height 5 ft., smaller dimensions than this being desirable. The parts of casement windows correspond in general to those of double-hung windows and are shown in Figs. 146*a* and *b*.

## ARTICLE 70. SOLID-SECTION METAL WINDOWS

Solid-section steel windows are constructed of light rolled-steel sections as shown in Fig. 147. They are divided into the following classes according to the provision made for opening: Pivoted windows, projected windows, horizontal-rolling windows, and counterbalanced windows. In general, the glass sizes are 12 × 18 in. and 14 × 20 in.

In *pivoted windows*, four, six or eight lights are arranged in a unit to form a ventilator which may be opened. In the *horizontally-pivoted* windows, the ventilator is pivoted on a horizontal axis near its center as shown in Fig. 147*a*. This type of ventilator is indicated by dotted diagonal lines drawn across the ventilator as shown in Figs. 147*a* and 148*a*, the intersection being in the center. In the *top-pivoted* windows, the ventilator is pivoted on a horizontal axis near its top. This type of ventilator is indicated by dotted lines meeting at a point near the top of the ventilator as shown in Fig. 148*b*. The ventilator of *vertically-pivoted* windows is pivoted on a vertical axis in the center of the ventilator. It is indicated by dotted lines drawn across the corners of the ventilator as shown in Fig. 148*c*. In the *side-hinged* or *casement* window, the ventilating unit is hinged at the side as shown in Fig. 148*d*. This type of window is indicated by two dotted lines drawn across the corners as shown in the figure and meeting on the side on which the ventilator is hinged.

In *projected windows* the ventilator is held in position by an arm on each side of the unit, one end of each arm being hinged to the ventilator and the other to the fixed part of the window, as shown in Fig. 147*b*. If the ventilator is to project out, the top of the ventilator moves down as the bottom swings out but if the ventilator is to project in, the bottom of the ventilator moves up as the top swings in. The method of indicating the projected-out and projected-in ventilators is shown in Fig. 148*e*, the dotted lines intersecting at the side which moves up and down and about which rotation takes place. Projected windows are of two general types: *commercial* and *architectural*. The commercial type is similar in appearance to pivoted windows. It is divided into small

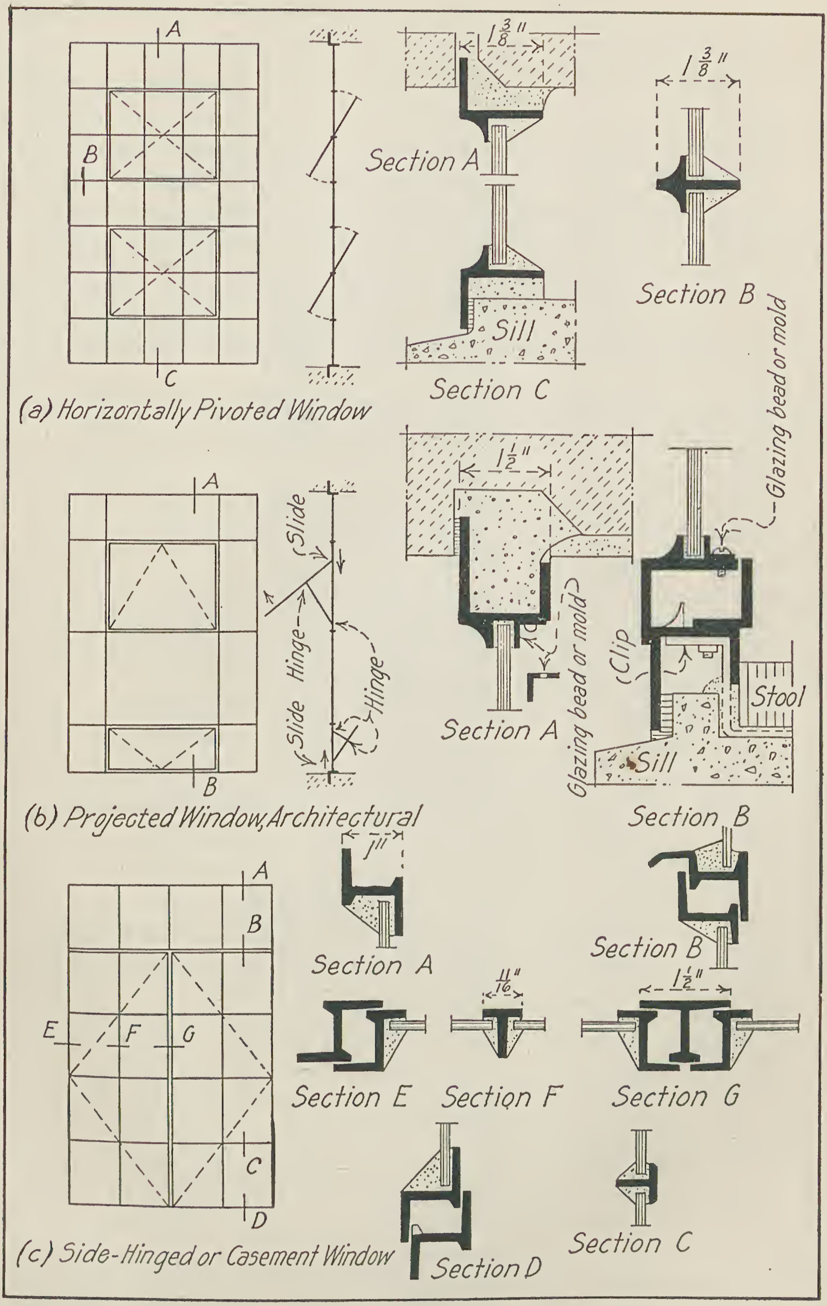


FIG. 147. Solid-section Steel Windows

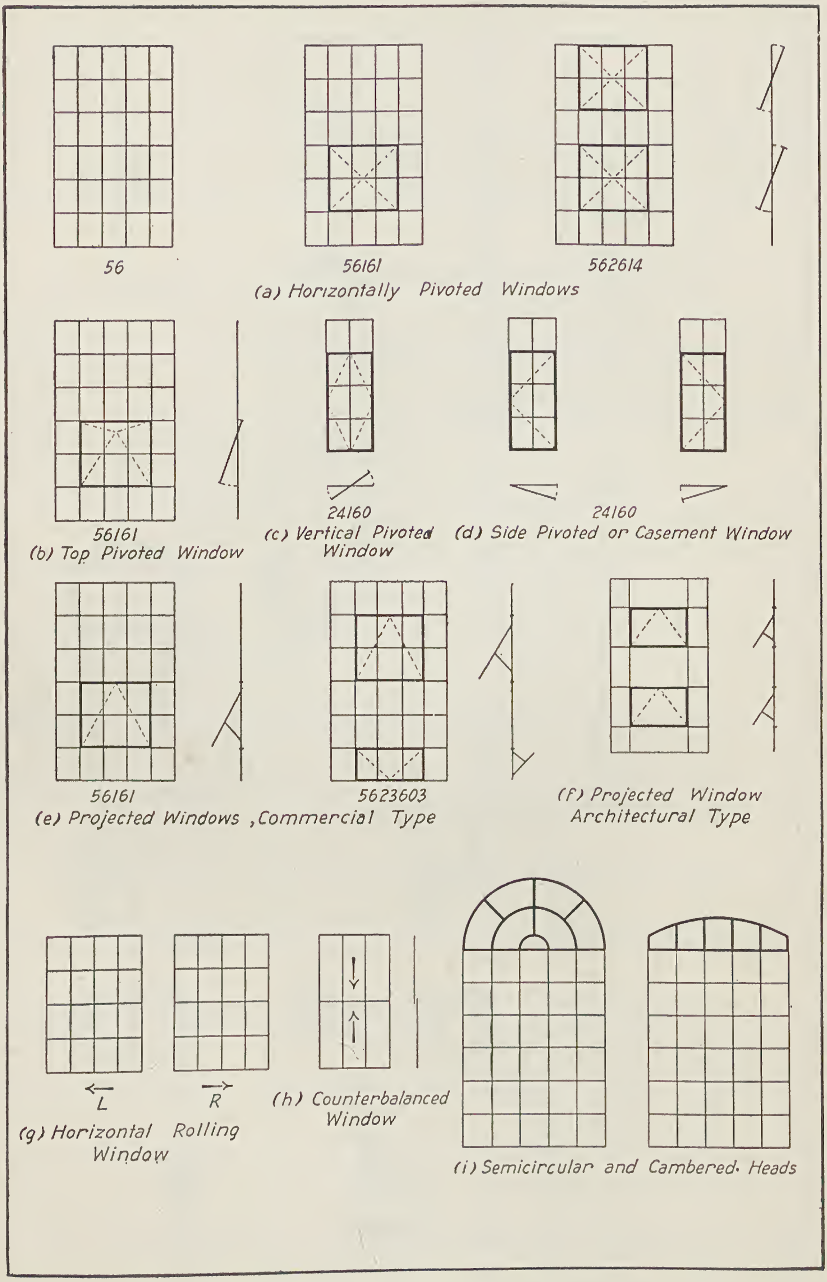


Fig. 148. Types of Solid-section Steel Windows

lights 12 × 18 in. or 14 × 20 in. in size. The architectural type as shown in Fig. 147*b* and 148*f* has a heavy outside frame which gives it a better appearance than the commercial type and the glass in the ventilator is in one sheet.

*Horizontal-rolling windows* are indicated as shown in Fig. 148*g*, the *L* or *R* indicating whether they roll to the left or right in opening.

*Counterbalanced windows* are indicated as shown in Fig. 148*h*.

Curved heads are available for use with most of the types of windows which have been described. They are either semicircular or cambered as shown in Fig. 148*i*. In general, they are bolted directly to the windows below but some of the wider semicircular heads require horizontal mullions.

Windows may be arranged side by side to form groups of any width by using vertical mullions between them. Standard rolled-steel mullions are available.

Screens are on the market for all types of ventilators.

Some of the methods used in fastening steel windows in masonry are indicated in Fig. 147. They may be built in as the masonry is laid but in general it is considered better practice to place them after the walls are completed, the necessary grooves and chases being left to receive them. If this practice is followed, they are fastened in the grooves with cement grout. Steel windows may be bolted to structural-steel sections where this method of fastening is convenient.

Pivoted windows, commercial projected windows, and horizontal-rolling windows are made up of several lights of equal size. The method of designating the size of window is of interest. The window number is made up as follows: The first digit is the number of lights wide, and the second the number of lights high. For instance, the first window in Fig. 148*a* is 5 lights wide and 6 lights high, so is designated 56. The third digit indicates the number of ventilators; the fourth, the number of lights in the ventilator if all of the ventilators are of the same size; the fifth, the number of rows of lights between the lower ventilator and the bottom of the window; and the sixth, the number of rows of lights between the upper ventilator and the bottom of the window. For instance, the second window in Fig. 148*a* is 5 lights wide, 6 lights high, has 1 ventilator with 6 lights, placed 1 light from the bottom, so its number is 56161. The third window in Fig. 148*a* has two ventilators of equal size. It is 5 lights wide, 6 lights high, has 2 ventilators, each with 6 lights, the lower one is placed 1 light from the bottom, and the upper one 4 lights from the bottom, so its number is 562614. The second window in Fig. 148*e* has two ventilators of unequal size. It is 5 lights wide, 6 lights high, has 2 ventilators, and one with 3 lights, one with 6 lights, the lower one

being 0 lights from the bottom, and the upper one 3 lights from the bottom so its number is 5623603. In these types of windows there are never more than two ventilators. The meaning of the dotted lines across the ventilators has been explained elsewhere.

The most common type of steel window for industrial buildings is the horizontally pivoted window shown in Fig. 147*a*. Top-pivoted and vertically-pivoted windows are used to a limited extent on industrial buildings. The use of projected windows of the commercial type in industrial buildings is increasing and the architectural type is being quite extensively used in the better class of buildings such as schools and office buildings. Horizontal-rolling windows are rarely used but counterbalanced windows are quite common in the better class of industrial buildings.

Side-hinged or casement steel windows with solid sections are growing in popularity for residences and apartment houses. They are usually out-swinging but in-swinging casements are available.

Double-hung counterweighted windows with solid steel sections are used in office buildings, schools, hotels, and other buildings of this class.

*Continuous windows* are very wide windows which are usually top-pivoted and are mechanically operated. They are used in monitors, in saw-tooth roofs and on the side walls of industrial buildings.

Solid-section metal windows are usually made of copper-bearing steel, but bronze is sometimes used for casement and double-hung windows in high-class buildings. Galvanized-steel windows are quite extensively used.

A standard nomenclature for solid-section steel windows is given in Simplified Practice Recommendation No. 72 of the U. S. Department of Commerce. In this nomenclature, the term *window* has been substituted for the term sash; the terms side-wall sash, rolled-steel sash, solid-steel sash, pivoted factory sash, standard steel sash, and solid-steel industrial sash have been replaced by the single term, *pivoted windows;* type B, reversible sash, projected sash industrial type B, and industrial projected sash are classed as *projected windows, commercial;* type A reversible sash, projected sash architectural type A, and architectural projected sash are classed as *projected windows, architectural;* and continuous sash and monitor sash are called *continuous windows.* This nomenclature has been adopted by a large number of manufacturers.

## ARTICLE 71. METAL-COVERED AND HOLLOW METAL WINDOWS

The common types of metal-covered windows are the double-hung and casement. The various parts of metal-covered windows are made of a non-resinous wood, such as white pine or cypress, with a tight-fitting

sheet-metal covering of furniture steel, galvanized steel, cold-rolled copper, sheet bronze or kalamein metal, which is steel with a thin coating of lead and tin and is called terne plate. The term kalamein is commonly applied to metal-covered wood regardless of the metal used. For example, wood covered with copper is frequently called copper kalamein.

Where it is possible to do so, the metal covering is drawn on the wood core through steel dies. The wood cores are accurately shaped and securely framed at all joints. In addition to the fire-resisting properties of metal-covered windows their resistance to moisture is an important feature. All joints and seams should be tight so that no moisture can reach the wood core.

Metal-covered windows in either the double-hung or the casement type are similar in shape and appearance to wood windows. They may be made to conform to the standards of the manufacturer or according to details which are furnished by the buyer.

Hollow metal windows are made of blue annealed steel, galvanized steel, bronze, copper, or nickel steel. They are usually of the double-hung or the casement type and are quite similar in appearance to wood windows.

Metal-covered windows are more expensive, more fire-resistant and more durable than wood windows and more attractive than solid-section steel windows. Hollow metal windows are more expensive than metal-covered windows. They are somewhat more fire resistant than metal-covered windows and are much more fire resistant than wood windows.

## ARTICLE 72. GLASS AND GLAZING

**Composition of Glass.** — Glass is composed of about six parts of white sand, one part of lime, and one part of soda with small amounts of alumina and other materials.

**Classification.** — Glass for glazing purposes is classified as follows by Specification No. 123 of the Federal Specification Board:

| | | |
|---|---|---|
| Polished plate glass | Second silvering quality. | |
| | Glazing quality. | |
| Clear window glass | Single strength.......... | A quality. |
| | | B quality. |
| | Double strength......... | A quality. |
| | | B quality. |
| | Heavy sheet............ | Glazing quality. |
| | | Factory-run quality. |
| Processed glass.... | Chipped................ | No. 1 processed. |
| | | No. 2 processed. |
| | Ground................. | Acid ground. |
| | | Sand blasted. |

| | | |
|---|---|---|
| Rolled figured sheet | Figured sheet. . . . . . . . . . . | Large variety of patterns. |
| | Colored figured sheet. | |
| Wire glass. . . . . . . . | Polished wire. | |
| | Polished (one side). | |
| | Figured. | |
| | Corrugated. | |
| | Colored. | |
| Ornamental. . . . . . . | Figured plate (polished one side). | |
| Prism glass. . . . . . . | Pressed tile. | |
| | Rolled sheet. | |
| | Rolled and pressed sheet. | |

**Definitions and Manufacture.** — The definitions and brief statements of the methods of manufacture of the various kinds of glass as given by Specification No. 123 of the Federal Specification Board are as follows:

*Plate Glass.* — Transparent, flat, relatively thin glass having plane polished surfaces and showing no distortion of vision when viewing objects through it at any angle. Plate glass is made at present by casting and rolling large sheets periodically or by rolling a continuous sheet. The sheets are then ground and polished.

*Clear Window Glass.* — Transparent, relatively thin, flat glass having glossy, fire finished, apparently plane and smooth surfaces, but having a characteristic waviness of surface which is visible when viewed at an acute angle or in reflected light. Clear window glass is made at present by hand blowing or by machine blowing and drawing into cylinders and flattening, or by drawing directly into a sheet, the surface finish being that obtained during the drawing process.

*Processed Glass.* — There are three kinds of processed glass either in plate or window glass, *viz.*, ground glass, chipped one process, and chipped two processes. The ground glass is made by either sand-blasting or acid etching of one surface. The chipped glass is made by applying either one or two coatings of glue to the ground surface.[1]

*Rolled Figured Glass.* — A flat glass in which the vision is more or less obscured either by the roughened surface produced in rolling or by the impression of a large variety of decorative designs in one surface of the sheet.

*Wire Glass.* — Rolled flat glass having a layer of meshed wire incorporated approximately in the center of the sheet. This glass is produced with polished or figured surfaces.

*Ornamental Plate.* — A figured plate glass made by rolling or rolling and pressing and having the plane surface ground and polished.

*Prism Glass.* — A flat glass having prism-shaped parallel ribs designed for deflecting light. This is made as a rolled plate or as a pressed plate, of which one side may be ground and polished, or as a pressed tile.

[1] The glue is applied hot and in cooling and drying shrinks and pulls small chips off of the surface of the glass.

**Thicknesses, Sizes, and Grades.** — The most common thickness of polished plate glass is $\frac{1}{4}$ in. to $\frac{5}{16}$ in. but $\frac{1}{8}$-in. and $\frac{3}{16}$-in. glass is fairly common. Other thicknesses up to $1\frac{1}{2}$ in. are obtainable by special order. Plate glass $\frac{1}{4}$ in. thick may be obtained in about any size up to 120 × 280 in., 144 × 260 in. or 160 × 240 in. Polished plate is available in two grades. Second silvering quality is used where the highest quality is desired but most of the glass used is known as glazing quality.

The most common thicknesses of clear window glass are *single strength* varying in thickness from $\frac{1}{12}$ to $\frac{1}{10}$ in. and *double strength* varying in thickness from $\frac{1}{9}$ to $\frac{1}{8}$ in. Other thicknesses up to $\frac{1}{5}$ in. are obtainable. Single strength is obtainable in sizes up to 40 × 50 in. and double strength up to 60 × 80 in. All clear window glass should be relatively flat but a slight regular curvature is not objectionable if it does not exceed 0.5 per cent of the length of the sheet. Glass with a reverse curve or which is crooked should be rejected. A small amount of "AA" quality window glass is sometimes selected for special purposes and may be obtained at a high price. The grade most commonly used in windows where appearance is an important factor is "A" quality but "B" quality is used quite extensively. Two grades inferior to "B" quality are on the market. They are "Fourth" quality and "C" quality. "Fourth" quality glass contains many defects and distorts the objects viewed through it. It should never be used where vision is a factor. "C" quality is too poor for use in buildings.

Rolled figured sheet glass is made in thicknesses from $\frac{1}{8}$ to $\frac{3}{8}$ in. and can be obtained in sizes up to 48 × 130 in. It is made in a great variety of surface finishes which obscure the vision, diffuse the light, and give decorative effects.

Wire glass is made in thicknesses from $\frac{1}{8}$ to $\frac{3}{4}$ in. the standard thickness being $\frac{1}{4}$ in. It is obtainable in sizes up to 60 × 144 in. Only one quality is manufactured for glazing purposes. It is made with polished surfaces and with a great variety of surface finishes which obscure the vision, diffuse the light and give decorative effects. The wire is in the form of a wire mesh the standard size of mesh being $1\frac{1}{4} \times \frac{7}{8}$ in. and the weight of wire No. 24 B & S gage.

The wire is placed in the glass by any of three methods: (1) by rolling a sheet of glass, placing the mesh on it while the glass is still plastic, pressing the mesh into the glass, and finishing the surface; (2) by rolling a thin sheet of glass, placing the mesh and rolling another sheet of glass on the first sheet; (3) by placing the wire on the casting table and holding it in position while the glass is poured around it. Polished wire glass is not of the same quality as polished plate glass.

**Special Glasses.** — A special glass, sometimes called actinic glass, has such composition that it excludes about 80 per cent of the ultra-violet rays and 50 per cent of the infra-red rays of light. This glass transmits a smaller amount of radiant heat than ordinary glass.

Bullet-proof glass is a special glass designed to prevent the penetration of bullets.

Ordinary window glass excludes a part of the ultra-violet rays of sunlight. These rays have a beneficial effect on the health. A special quartz glass which transmits a large percentage of these rays is on the market.

**Selection of Glass.** — Polished plate glass is used for exposed windows in the better grades of buildings. It is much superior to window glass in appearance and in the clearness of vision through it but is much more expensive. Large windows, such as show windows, are always made of polished plate glass.

Clear window glass is extensively used in all classes of buildings.

Chipped and ground glass are used to a limited extent where light is to be admitted but vision is to be obscured. Chipped glass is more attractive than ground glass and is used in interior partitions. Rolled figured glass serves the same purposes as chipped and ground glass, is usually cheaper, and designs which are more attractive are available.

Rolled figured glass is extensively used on the exterior and interior of buildings when it is desired to obscure the vision or diffuse the light. Many attractive designs are available and the cost is less than clear window glass.

Wired glass is used in outside windows because of its resistance to fire. When heated and drenched with water it will crack but due to the action of the wire mesh it will remain in position and protect the interior of a building from fires originating outside. Wired glass is also used in doors and in other positions where breakage is likely to occur. It will continue to give service even though badly fractured.

Prism glass is used where it is desired to light areas which are remote from a window. Light striking the glass is deflected so that it is effective for a considerable distance away from the glass. A common use for prism glass is in the upper part of store windows where the stores are deep and windows are in the front only.

**Glazing.** — The process of placing glass in the sash is known as *glazing.* Rebates $\frac{1}{4}$ in. or more in depth are provided in the sash to support one side of the glass. After the glass is placed in position it is held by means of putty or glazing beads, strips or molds made of wood for wood sash and metal for metal sash as shown in Figs. 145, 146, and 147.

Putty for wood sash should be made of linseed oil and whiting with or

without the addition of white lead as described in Article 86. In hardening, a part of the linseed oil is absorbed by the wood in contact with the putty and the remainder hardens by oxidation.

Putty which is suitable for wood sash will not give good results when used with metal sash because the sash will not absorb linseed oil. For this reason about 5 per cent of litharge is used in putty for steel sash to assist in the hardening by promoting the oxidation of the linseed oil. Special putty for metal sash is on the market and, if of good quality, is preferable to ordinary putty to which red lead has been added.

The puttied face of wood sash is placed outside. Before the glass is set, it is desirable to place putty on the rebate of the sash. The glass is then pressed into the putty to an even bearing. This operation is known as *bedding*. The glass is held in position by small triangular or diamond shaped pieces of steel metal called *glaziers' points* which are forced into the sash and bear against the glass. The remainder of the rebate is then filled with putty and smoothed off by use of a putty knife. This is called *face puttying*. *Back puttying* consists of forcing putty into any spaces which may be left between the edges of the rebate and the glass. Glaziers' molds are usually used instead of face putty for glass in doors.

On steel windows the putty surface is usually on the inside but may be on the outside. In the more expensive grades of metal sash, metal molds or strips are usually used instead of face putty. The glass is preferably back-bedded and back-puttied.

Window glass may be slightly curved and still be acceptable. It should be set with the convex face out. Plate glass in large lights should be supported by a felt, leather, lead, or softwood pad near each end and should be held in position by molds which do not grip it too lightly for otherwise the glass may break.

Windows are sometimes provided with two thicknesses of glass with an air-space of from $\frac{1}{4}$ to $\frac{1}{2}$ in. between them. This is known as *double-glazing* and is done to reduce the heat losses, or an outer glass of polished plate or window glass is provided to protect leaded glass or glass of other ornamental design.

## REFERENCE

Sweet's Architectural Catalogue, published by the F. W. Dodge Corporation, New York City, contains the advertisements of various window manufacturers in convenient form for reference.

## CHAPTER XIII

# STAIRS

### ARTICLE 73. DEFINITIONS AND GENERAL DISCUSSION

**Definitions.** — A series of steps without an intervening platform, called a *landing*, is called a *flight*. A *stair* is a series of steps, or flights of steps connected by landings, for passing from one level to another. The space in a building occupied by the stair is called the *stairway*, but this term is often used in the same sense as stair. A staircase includes the entire group of stairs from the bottom floor to the top floor. This term is often used with the same meaning as stair.

The various parts of a stair are shown in Figs. 149*a* and *b* and may be defined as follows:

The *tread* is the horizontal top surface of a step or the member forming this surface. The *riser* is the vertical face of a step or the member forming this face. Usually the tread projects a short distance in front of the riser forming the *nosing*.

The *rise* of a step is the vertical distance between treads and the *run* is the horizontal distance between risers and is equal to the width of tread not including the nosing. The terms rise and run are also applied to the corresponding dimensions of a flight of steps. A step whose tread is narrower at one end than the other is called a *winder*. A step with one or both ends rounded in a quarter of a circle and ending at the newel or a step with semicircular ends with the newel at the center is called a *bull-nose step*.

The posts set at the top and bottom of a stair and supporting the stair-rail are called *newels* or *newel posts*. The intermediate posts at turns in a stair are also called *newels*. The vertical members running between the ends of the steps and the rail are called *balusters*. The parts of a rail located at points where the direction of the rail changes without running into a newel are called *ramps*, *easings*, and *goosenecks* or *wreaths*, depending upon their shape as shown in Fig. 150.

The inclined member to which the ends of treads and risers are fastened is called the *string*. An *outside string* is a string which is not located against a wall. A *wall string* is located against a wall. The upper edge of a *closed* or *curb string* is a continuous line conforming to the slope of the stair as shown in Fig. 149*b*. If the top edge of a string is notched to follow the treads and risers it is called an *open string*. See Fig. 149*a*.

Inclined surfaces used for foot or vehicle traffic are called *ramps*.

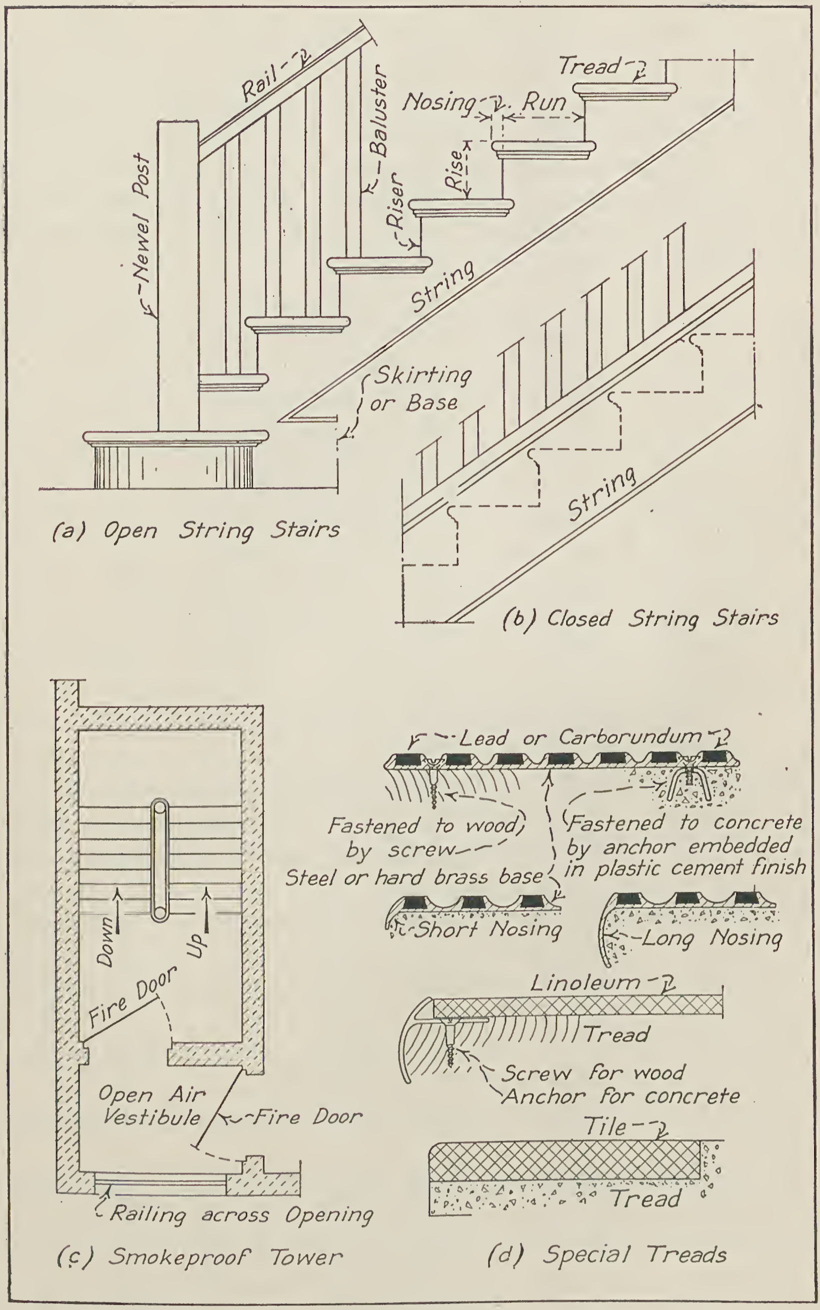


FIG. 149. Wood Stairs and Stair Details

They are used in preference to stairs where large numbers of people are to be accommodated as in railway stations, stadiums, etc.; in multi-story garages they replace elevators, and their use for many industrial purposes is increasing. The space occupied by ramps is much greater than that required by stairs because of the flat slope which is necessarily used with ramps. The slope of ramps for foot traffic should not exceed 1 in 8 but a slope not greater than 1 in 10 is preferable. Hand rails should be provided when the slope exceeds 1 in 10. Ramps should be surfaced with some non-slip material.

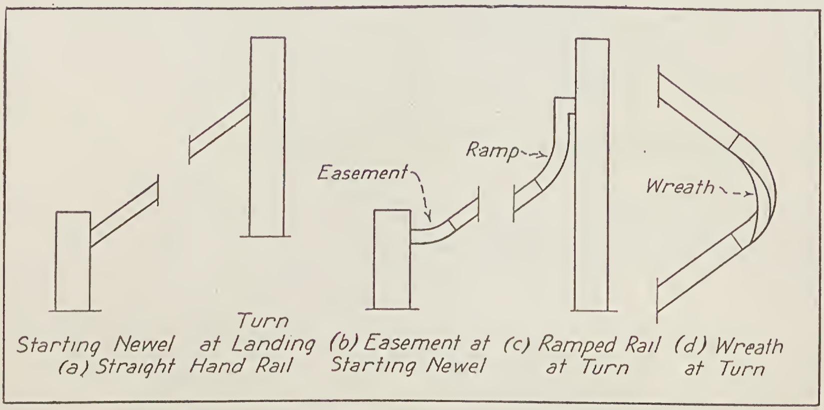


FIG. 150. Stair Rails, Easements, Ramps and Wreaths

**Proportioning Stairs.** — The rise and run of a stair are determined by arbitrary rules. It is recognized that, for comfort in using a stair, the run must be increased as the rise is decreased. Four of these rules are as follows:

The sum of the rise and run should not be less than 17 in. nor more than 18 in.

Twice the rise plus the run should not be less than 24 in. nor more than 25 in.

The product of the rise and run should not be less than 70 nor more than 75.

The product of the rise and the square root of the run should be equal to $23\frac{1}{2}$.

For important stairs a rise of 7 in. and a run of 11 in. will give satisfactory results while in residences a rise of 7 or $7\frac{1}{2}$ in. and a run of 10 in. or even $9\frac{1}{2}$ in. may be used, and unimportant stairs such as those leading to basements are often made with both run and rise equal to 8 in. A rise greater than 8 in. is always objectionable. The nosing may project from $\frac{3}{4}$ in. to $1\frac{1}{2}$ in.

The pitch or slope of long stairs should be made flatter than would ordinarily be satisfactory, and landings should be introduced to make the stair less tiresome and less dangerous. The flights between landings should not exceed 12 ft. in height, and the width of landing should be wider than the tread by an amount equal to the average length of step, or multiple of this length. The length of step on a landing is less than on the level and may be taken as about 2 ft. The pitch of short flights out-of-doors should be less than that used inside on account of the more rapid pace naturally used out-of-doors. A 6-in. rise and 12-in. run are satisfactory under these conditions.

The width of stairs is determined by their importance and by the number of people who may be expected to use the stair and whether or not they may come in large groups. In general, stairs should be at least 3 ft. wide to accommodate two persons side by side, but unimportant stairs which have a limited use may be made narrower. The Building Code of the National Board of Fire Underwriters states that the width of stairways required for any floor area above the first floor shall be determined by the number of persons occupying such floor area, computed on the basis of 14 persons for each 22 in. of width of stairway, plus 1 person for every 3 sq. ft. of hallway floor and stairway landings in the story height of such floor.

Public stairways 7 ft. or over in width should have a continuous center rail. The average height of a rail should be about 2 ft. 6 in.

**Fire Exits.** — There are two types of exits from buildings for use in case of fire: horizontal exits and stair exits. Horizontal exits provide a passageway through an opening in a fire wall or a fireproof wall separating two buildings. These openings should be provided with self-closing fire doors. Horizontal exits may be provided around a fire wall or around a wall separating two buildings, by a balcony constructed of non-combustible material, or they may cross a space between two closely spaced buildings by means of a bridge.

Stair exits may be interior stairs enclosed in a fireproof stairway, stairs in smoke-proof towers, or outside stairways.

The following recommendations concerning fire exits are made in *Concrete, Plain and Reinforced* by Taylor, Thompson, and Smulski:

> In all business buildings at least two fire exits should be provided for every floor above the first, irrespective of the number of occupants of the floor. One of these should be a stair-exit, while the other may be a horizontal exit. These exits should be arranged so that no part of any floor area shall be more than 100 ft. distant from a horizontal exit or an entrance to a staircase. Additional exits should be used if the number of occupants of any one floor served by the exits exceeds the capacity of the two exits.

In all fireproof buildings that are more than three stories high or occupied by more than fifty persons above the first floor, at least one of the stairways should be continuous and in a fireproof enclosure. This should lead either to the street, alley, or open court, or to a fireproof corridor, of proper width, to the open air.

The National Board of Fire Underwriters requires a smoke-proof tower, or a horizontal exit for buildings over 90 ft. in height.

A smoke-proof tower is shown in Fig. 149*c*. The stairway is separated from the rest of the building by an open air vestibule so that it cannot become filled with smoke.

**Special Treads.** — On account of the excessive wear on stair treads, and to avoid the danger of slipping, special treads of various materials are manufactured for use on stairs. Many types of such treads, as shown in Fig. 149*d*, are on the market. One consists of an abrasive material embedded in the wearing surface of a cast-iron, bronze, or aluminum tread. In another type the abrasive material is embedded in a clay-tile tread. Strips of lead or lead slugs may be embedded in steel, cast-iron, or brass bases. Rubber, linoleum, and cork treads are used, but they should be protected by a metal nosing as shown in the figure.

Treads and risers for steel and concrete stairs may consist of slabs of bluestone, slate, or marble. Such treads should always be supported throughout their length by steel members or concrete because if exposed to fire they may become weakened and break just when they are most needed.

Steel checkered plates may be used for the treads of steel stairs.

**Railings.** — Stair railings may be of various designs. They may consist of a wooden rail and balusters; a wood rail and wrought-iron or steel balusters; ornamental wrought iron or steel arranged in various designs; solid plaster with wood or metal rail; pipe rails; solid stone, or brick rails; and stone railings with stone balusters. Hand rails to be used along a wall are sometimes called *grab rails.*

The type of railing which is appropriate for a given stair will depend to a large extent on the type of construction used for the stair. The various types of stairs are described in the articles which follow.

## ARTICLE 74. WOOD STAIRS

Several methods are used in the construction of wood stairs. One of the most common methods will be described in this article.

**Rough Framing.** — The rough framing required for the support of a wood stair is illustrated in Fig. 151*a*. It consists of *carriages* accurately cut to receive the treads and risers. A carriage which goes next to a wall should be kept about 3 in. away from the wall so that it will not

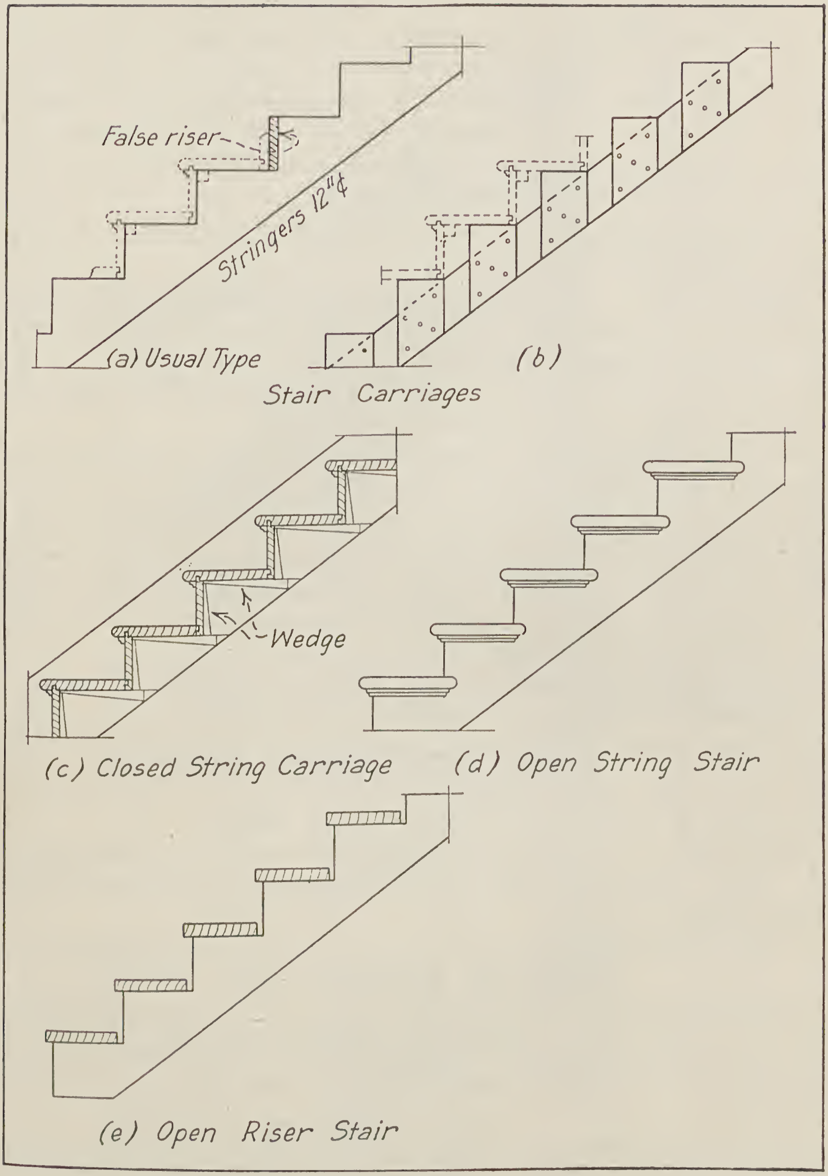


FIG. 151. Types of Wood Stairs

interfere with the wall string to be placed later. Carriages are constructed of 2-in. or 3-in. material and should be of sufficient strength to carry the load which they are to receive. They are usually spaced 12 in. center to center. On long flights, *false risers* are used on every fifth or sixth step to stiffen the structure. In this case, the carriages should be cut so that this riser will clear the finished riser. Rough treads are placed so that the stairs may be used during construction, but these are removed before the finished treads are placed.

Occasionally carriages are constructed as shown in Fig. 151*b*, but this type is undesirable.

**Finished Stairs.** — The finished stairs are prepared at the mill and are placed after the plastering is completed. The ends of the finished treads and risers are housed in a wall string or closed string as shown in Fig. 151*c*, provision being made for wedges which are driven up tight and glued to hold the treads and risers firmly in place.

Open string construction is illustrated in Fig. 151*d*. The string is cut to receive the treads and risers; the nosing is mitered and returned to finish the exposed end of the tread; the riser is mitered with the string; and the lower end of the balusters is dove-tailed, or doweled to the tread. Tongue-and-groove joints are usually provided at the junctions of the risers and treads, and blocks may be glued or screwed in the interior angle between the risers and treads.

The treads should usually be $1\frac{1}{8}$ in. thick and the risers $\frac{7}{8}$ in. thick.

**Materials.** — On account of the severe wear to which treads are subjected they should be made of oak, birch, maple, or yellow pine. Oak and yellow pine should preferably be quarter-sawed. The risers and other parts of the stair may be of softwood if desired.

**Plank Stair.** — A rough stair constructed of planks is illustrated in Fig. 151*d*. It is of open riser construction with plank treads notched in plank strings.

## ARTICLE 75. CONCRETE STAIRS

Reinforced-concrete stairs are extensively used in fireproof buildings. They are usually placed after the structural frame has been completed, so recesses and ties should be provided in the structural frame to receive the stairs.

**Structural Details.** — A simple flight of reinforced concrete is illustrated in Fig. 152*a*; a flight ending at a landing in Fig. 152*b*; a flight beginning at a landing in Fig. 152*c*; and a flight beginning and ending at a landing in Fig. 152*d*. Particular attention should be paid to the position of reinforcement at an interior angle on the tension side. If the reinforcement follows around the tension side of the stair slab at the angle

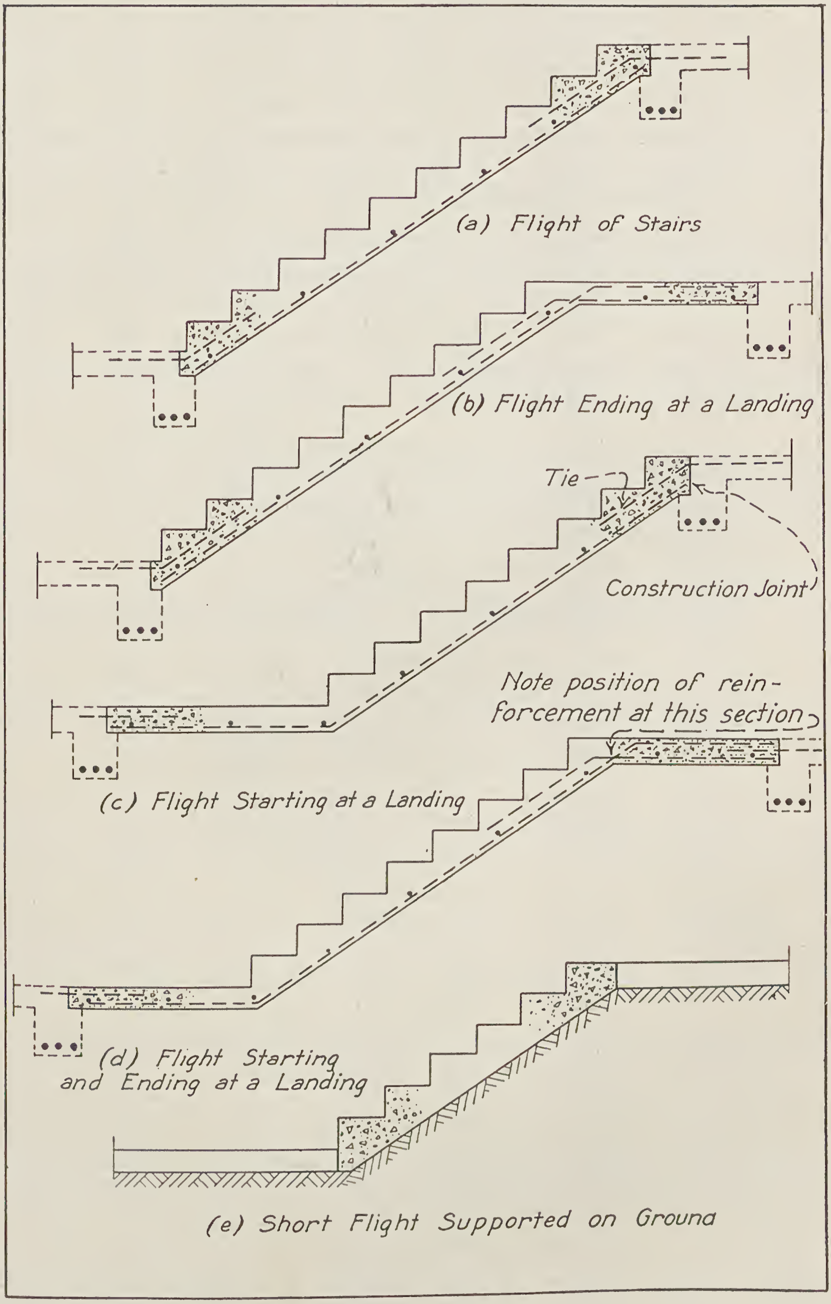


FIG. 152. Concrete Stairs

it will tend to straighten out and separate from the slab. The drawings show how this can be avoided. In Figs. 152*b* to *d*, the stair and the landing act together as a bent slab supported at each end. Instead of being designed as an integral part of the stair the landing may be supported by beams running between walls enclosing the stairs, by beams suspended from the structural frame of the floor above, or by beams supported by props resting on the structural frame of the floor below. Short flights are frequently supported on the ground as shown in Fig. 152*e*.

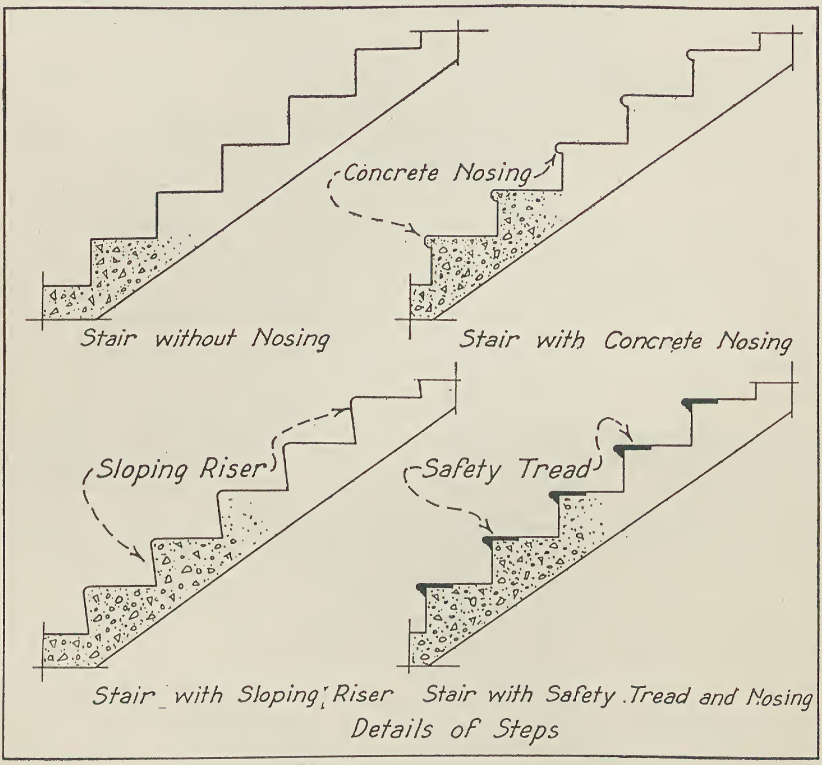


Fig. 153. Types of Concrete Stairs

Concrete is probably the most suitable material for stairs of complicated design, such as winding stairs. Circular or spiral stairs similar to the stone stairs shown in Fig. 157*a* are constructed of precast steps.

**Details of Steps.** — Various details of steps are illustrated in Fig. 153. The simplest type of step has a vertical riser, and the tread is without a nosing, but this detail should not be used on important stairs. The effect of a nosing can be secured at little expense by sloping the riser outward at the top. One form of cast-iron tread provides the nosing and

thus simplifies the formwork. The nosing can be formed of concrete and can be used with or without a special tread. Other types of treads, as described in Article 73, can be used with concrete stairs. A terrazzo finish is frequently used on concrete stairs where appearance is an important factor.

### ARTICLE 76. STEEL AND CAST-IRON STAIRS

Steel stairs are of three general types. The simplest type consists of strings of steel channels and treads of steel checkered plate, concrete supported on steel angles or channels, or steel grating as shown in Fig. 154*a*. The risers are usually open and the treads are fastened to the strings by light shelf angles. The railings and posts may be of angle irons or a pipe rail may be used. Stairs of this type are suitable for use in industrial buildings.

Another type of steel stair consists of strings of steel channels or plates, and risers and structural treads formed of steel plates, all finished in such a manner as to be suitable for use in high-class buildings. Typical details of this type of stair are shown in Fig. 154*b*, but a large number of designs are on the market. Stairs of this type are supplied by manufacturers making stair-building a specialty. The illustration shows treads of various materials supported by the sub-tread consisting of a steel plate. The railings in this type are made attractive in design to suit the rest of the stair.



The third type consists of steel strings and precast reinforced-concrete combination tread and riser as shown in Fig. 154*c*. Spiral stairs as shown in Fig. 155 are only suitable for use where they will receive very little traffic and where the space available is small. They are commonly made of cast-iron winders arranged around a pipe newel, but types consisting of cast-iron treads and steel winders are on the market.

### ARTICLE 77. STONE AND BRICK STAIRS

**Method of Support of Stone Steps.** — Stone stairs may consist of steps supported at both ends by masonry walls, as shown in Fig. 156*a*. One end may be built into a masonry wall leaving the other end free forming *hanging steps* as shown in Fig. 156*b*, or the stair may be circular in plan with winders, the outer end being supported by a wall and the other by a central newel formed by the inner ends of winders as shown in Fig. 157*a*.

**Shape.** — Steps may be approximately rectangular in cross-section, as shown in Fig. 156*c*, or approximately triangular in section as shown in Fig. 156*d*, each step bearing about 2 in. on the step below. The steps with triangular cross-section are called *spandrel steps* and have the ad-

vantage of lighter weight and are more attractive in appearance when the under side, called the *soffit*, is exposed. The ends of spandrel steps are made rectangular in cross-section where they are built into the supporting wall.

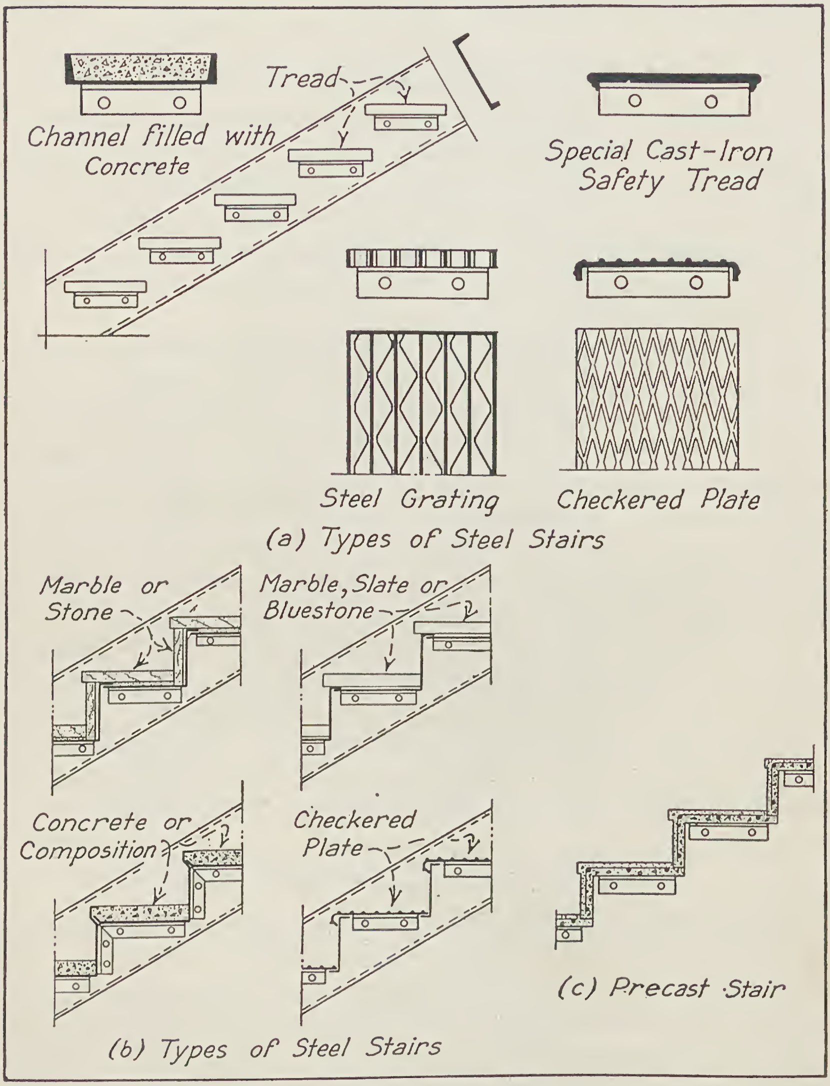


FIG. 154. Types of Steel Stairs

**Hanging Stairs of Stone.** — The method of support of hanging steps may need further explanation. Each step is supported at one end by the wall in which it is embedded and at the free end by the step below, on

which it rests. If the support at the wall were sufficiently rigid this design would be satisfactory, but a slight yielding at the wall would permit the steps to move in the horizontal direction. This is prevented by notching the steps as shown in Fig. 156*b*, so that each step is restrained

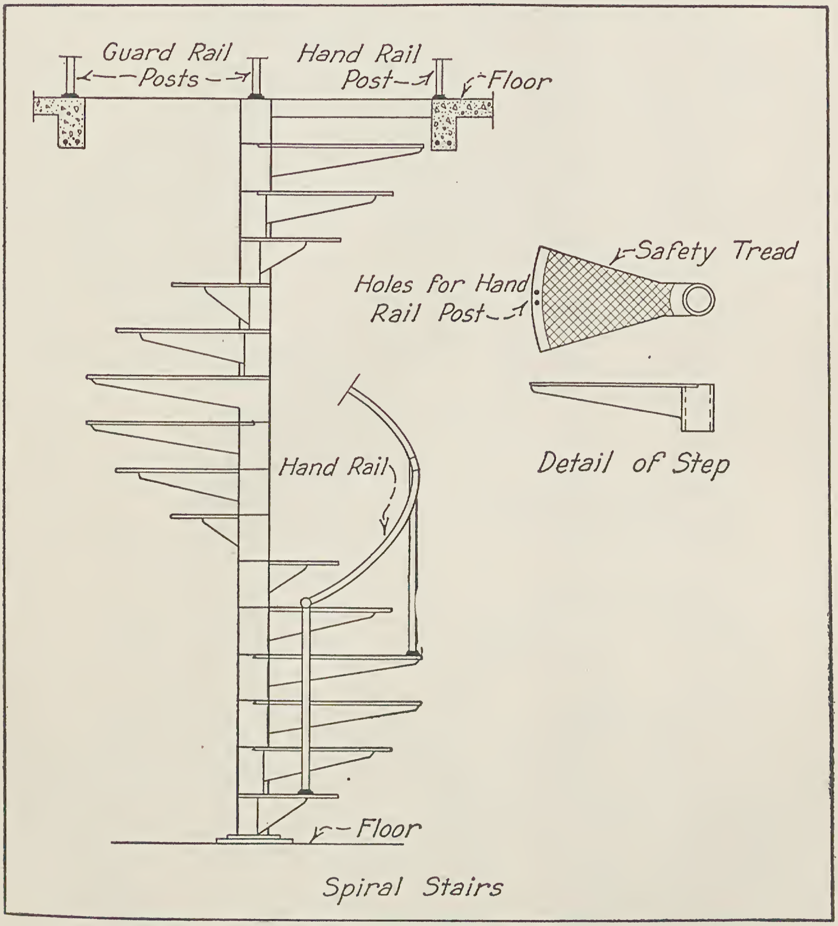


FIG. 155. Cast Iron Spiral Stairs

from moving horizontally and vertically. The top and bottom of the stair must be arranged to resist horizontal movement, and the bottom must carry the accumulation of vertical load from all of the steps.

For long flights it may be necessary to provide additional support for the free end by means of a bracket or steel cantilever beams projecting from the wall at intervals; or a steel or reinforced-concrete string may be used, in which case the stair is no longer of the hanging type. Hanging

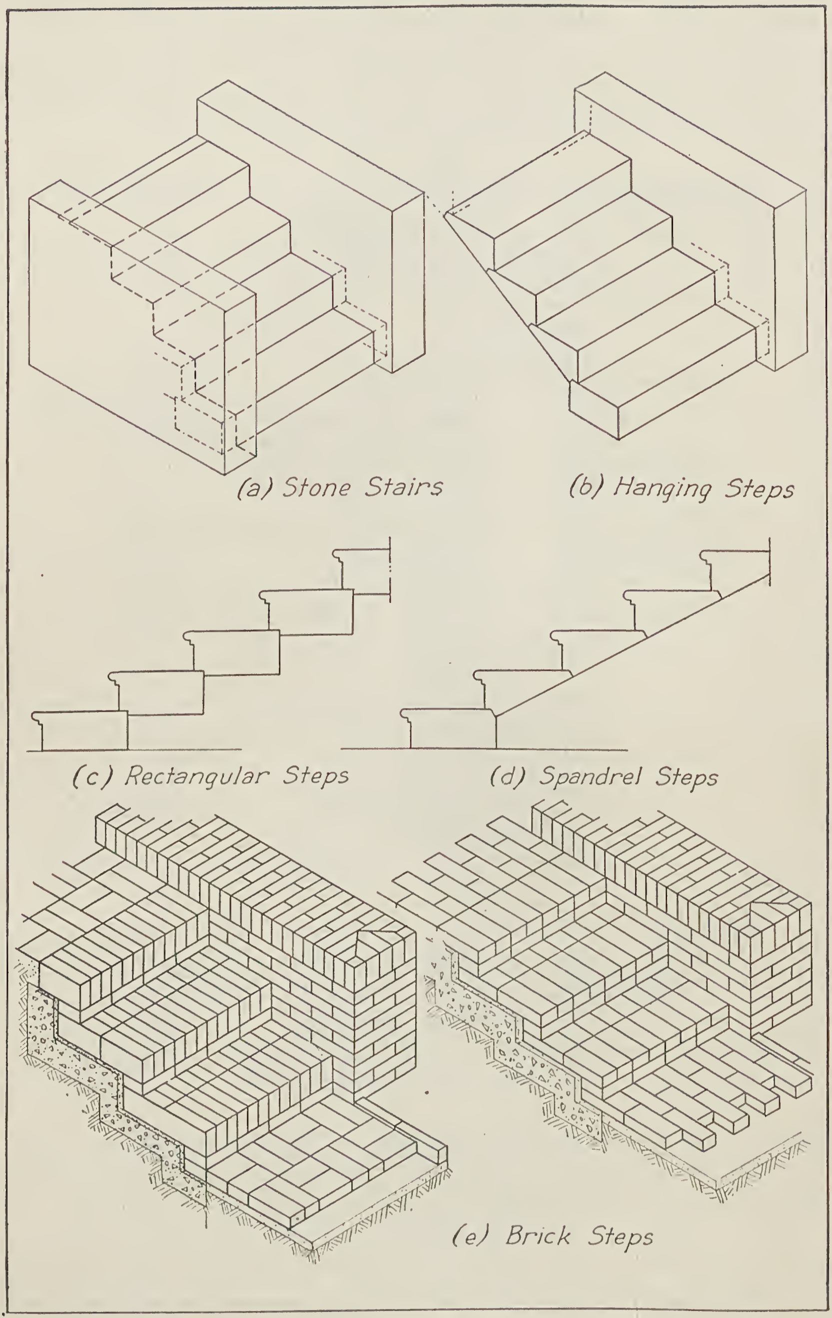


FIG. 156. Stone and Brick Stairs

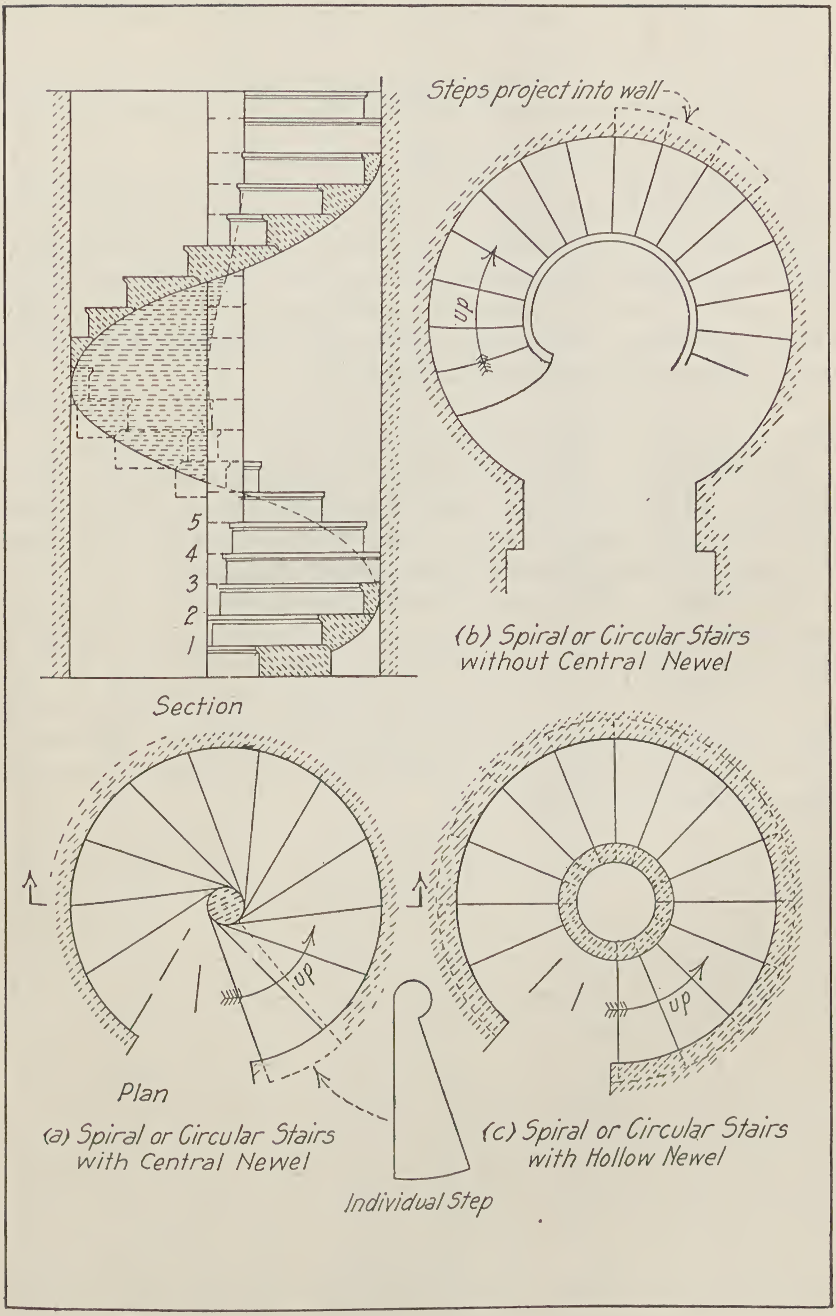


FIG. 157. Stone Spiral or Circular Stairs

steps are always of the spandrel type on account of their being lighter and because of the more attractive soffit which they form.

A special case of the hanging stair is that of the circular stair with an open well instead of a newel as shown in Fig. 157*b*. A spiral stair with a hollow newel is shown in Fig. 157*c*.

**Placing the Steps.** — The ends of the steps may be built in the masonry walls as the work progresses, they may be supported on corbels, or recesses may be left in the walls to receive the steps which may be placed later. It is evident that corbels cannot be used with hanging steps and that great care must be taken in securing the ends if these steps are placed in recesses. In any case, the free ends of hanging steps should be supported until the mortar has thoroughly set.

Outside steps should be placed with the treads pitched slightly forward to provide a wash in order that they will drain properly.

**Kind of Stone.** — The stone used for steps must have superior wearing qualities. Granite is the most satisfactory in this respect, but some sandstone, limestone, and marble may be used with good results. Stone used for outside steps is subjected to severe weathering action.

**Brick Steps.** — Short flights of brick steps supported by concrete are used out-of-doors to a considerable extent. Two methods of construction are illustrated in Fig. 156*e*. The steps should pitch forward with a slope of about $\frac{1}{4}$ in. per ft. to provide drainage, they should be hard, durable brick laid in rich cement mortar with a slightly concave joint thoroughly rubbed with a steel jointing tool. The front of the treads should be laid of full headers.

## CHAPTER XIV

# PLASTER AND STUCCO

### ARTICLE 78. DEFINITIONS AND GENERAL DISCUSSION

**Definitions and Uses.** — *Plaster* is a material used in a plastic state, which can be troweled, to form a hard covering for *interior* surfaces, walls, ceilings, etc., in any building or structure.[1]

*Stucco* is a material used in a plastic state, which can be troweled, to form a hard covering for *exterior* walls or other exterior surfaces of any building or structure.[1]

**Materials.** — The mortar used in plastering interior surfaces is made of sand and water mixed with lime, gypsum plaster, Keene's cement, or portland cement as a cementing material. On exterior surfaces, portland cement stucco and a special preparation called magnesite stucco are used. For detailed description of the materials used in plaster and stucco, see Article 5.

**Bases.** — Plaster and stucco are applied to bases of brick, stone, hollow tile, or concrete masonry, and to wood lath, metal lath, and plaster board or similar materials furnished in sheets.

**Placing.** — The mortar is applied with a special *trowel* and is brought to a true surface with a *darby* and a long straight-edge called a *rod.* These tools are illustrated in Fig. 158*a*. Wood or metal *grounds* are placed around all openings and along the top of the wall base, as shown in Fig. 158*b* and *c*, to serve as guides in finishing the plaster. These guides may also serve as nailing strips for the wood finish. It is also necessary for a plasterer to build up guides of plaster to assist in securing a true surface. Such a guide is called a *screed.* It is a part of the brown coat. The surface may be finished with the steel trowel to give a smooth finish, it may be finished with a rough *float* to give a sand finish, or special finishes may be formed in various ways.

**Coats.** — Three coats of plaster are usually applied on wood or metal lath. The first coat is called the *scratch coat* because its surface is scratched to give a better bond to the second coat, which is called the *brown coat* on account of its color. The brown coat is finished accurately to a true surface ready to receive the finish coat. The surface of the brown coat is formed by a straight-edge, called a *rod*, which is worked up and down with the lower end bearing against a ground along the bottom

[1] Standards of American Society for Testing Materials.

of the wall and its upper end bearing against a screed built up of plaster. It is usually necessary to place a screed at the mid-height of a wall with ordinary ceiling heights because it is not feasible to plaster the entire height in one operation, the upper part requiring a scaffold. Specifications sometimes require that the vertical distances between horizontal screeds shall not exceed 5 ft. In cheap work screeds are usually omitted.

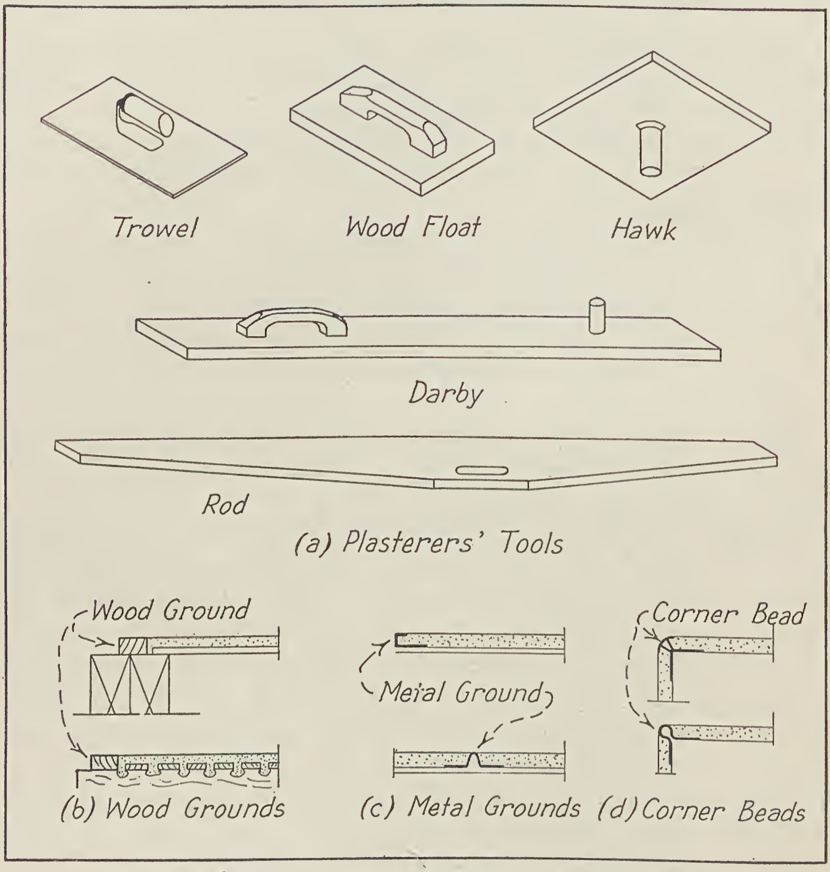


FIG. 158. Plasterers' Tools, Grounds, and Corner Beads

The *finish coat* is often called the *white coat, skin coat,* or *putty coat* and will be described later. Usually each coat is permitted to dry out thoroughly before the next coat is applied, but in order to save scaffolding the brown coat is sometimes applied immediately after the scratch coat. This is called *drawn work* or *laid off work* and is not as satisfactory as that obtained by the usual method.

In cheaper work on lath, the scratch and brown coat may be combined

into one coat, placed in one operation, and finished ready to receive the finish coat. This is called two-coat work.

On brick, stone, hollow tile, and other classes of masonry the scratch coat is not required but is often used.

The total thickness of the plastering usually varies from $\frac{1}{2}$ in. to $\frac{3}{4}$ in. though in some cases a thickness of $\frac{7}{8}$ in. is required. In filling out irregularities, and in making walls plumb a greater thickness is often necessary. A common requirement for the thickness of grounds is $\frac{3}{4}$ in. for $\frac{1}{4}$-in. plaster board, wood lath, and metal lath; $\frac{7}{8}$ in. for $\frac{3}{8}$-in. plaster board, and $\frac{5}{8}$ in. for brick and hollow tile walls. The grounds are so placed that they include the thickness of the lath and plaster board as shown in Fig. 158*b* and *c*. The vertical external corners of plaster are protected by *corner beads* as shown in Fig. 158*d*.

**Ornamental Plastering.** — Ornamental features may be applied in two ways. Such linear members as cornices, coves, and moldings are *run* in place, the outlines being cut into the wet plaster by sheet-metal templets. Designs which cannot be run are *cast* in molds and then placed in position.

## ARTICLE 79. BASES FOR PLASTER AND STUCCO

The various plaster and stucco surfaces described in Article 80 may be applied to many types of bases as shown in the following classification:

1. Masonry
    - (*a*) Brick, stone, and concrete
    - (*b*) Hollow tile, and gypsum blocks
2. Wood lath
    - (*a*) Common wood lath
    - (*b*) Wood lath in combination with asphalt felt, called "Bishopric Board" (a patented product)
    - (*c*) Grooved sheathing lath called "Bykrit Lath"
3. Metal lath (as classified by Associated Metal Lath Manufacturers)
    - (*a*) Expanded metal
        - (1) Diamond and rectangular mesh
        - (2) Ribbed lath
        - (3) Corrugated lath
    - (*b*) Integral lath
        - (1) Expanded metal
        - (2) Sheet metal (not expanded)
    - (*c*) Sheet lath
        - (1) Flat perforated
    - (*d*) Wire lath
        - (1) Plain
        - (2) Stiffened
4. Plaster board and fiber board.

**Masonry.** — Plaster may be applied directly to brick, stone, and concrete masonry. Two coats only are usually required, the brown coat and the finish coat, but it is often necessary to fill in irregularities in a stone wall before the brown coat is applied. Many architects specify a special bond plaster for concrete surfaces.

Except in very dry climates, plaster should not be applied directly to the inside surface of brick, stone, or concrete exterior walls because driving rains will soak through the walls, and stain the plaster or cause it to fall off. Condensation of the moisture in the atmosphere of the rooms on the cold inner surfaces of outside walls also causes trouble. For these reasons and to provide better insulation, an auxiliary surface to receive the plaster is constructed on the inside of the exterior walls. This is known as wall furring and provides an air space between the masonry wall and the plastered surface. For methods of furring, see Article 17.

Interior partitions are very commonly constructed of hollow tile or gypsum blocks as described in Article 20. The surfaces of these blocks are roughened or scored to form a better bond with the plaster. Portland cement plaster will not adhere to gypsum blocks. Hollow clay tile is used for exterior walls and on account of the air space in the tile may not require furring, but furring is desirable in this case also. Gypsum blocks are never used for exterior walls because they will not withstand the action of water.

**Wood Lath.** — Wood lath are made of white pine, yellow pine, redwood, cypress, fir, and spruce. They are $\frac{1}{4}$ or $\frac{3}{8}$ in. by $1\frac{1}{2}$ in. in section and are commonly 48 in. long but are also manufactured in 32-in. lengths. They are laid $\frac{3}{8}$ in. apart on ceilings and $\frac{1}{4}$ in. on side walls so that the plaster may be forced partly around the lath forming a key as shown in Fig. 158*b*.

Wood lath are cheaper than metal lath but are not as satisfactory on account of their combustibility and because plaster applied over wood lath is more likely to crack than when applied over metal lath. Wood lath are usually fastened directly to wood studding spaced 12 in. or 16 in. but they are also used on exterior walls over wood sheathing. In this case 1-in. by 2-in. furring strips spaced 12 in. or 16 in. should be used to give a space behind the lath for the plaster to form a key.

Wood lath should be wet thoroughly so that they will swell before the plaster is applied. If this precaution is not taken the lath will absorb water from the plaster and swell, thus causing cracks in the plaster.

Dove-tailed wood lath mounted on an asphalt-covered fiber board, are on the market. The dove-tailed lath afford a better grip on plaster than is secured with ordinary lath. The asphalt-covered fiber board is air-

tight and damp-proof. This material is available in different weights and may be obtained untreated or treated with a preservative. It is shipped in rolls containing one sheet 4 ft. wide and 25 ft. long. This board may be used as a base for interior or exterior plaster or stucco. It may be nailed directly to wood studding or may be placed over wood sheathing. If placed over horizontal wood sheathing the strips should be placed vertical. Their use with diagonal sheathing is not recommended. This is called Bishopric Board and is a patented product.

A special patented form of wood lath consisting of sheathing 4 in. or 6 in. wide with dove-tailed grooves about 1 in. wide and $\frac{1}{4}$ in. deep is known as Byrkit Lath. It may be applied directly to wood studding to form a base for stucco on outside walls. A layer of building paper should be used between the studs and the lath. A tight wall is secured if ordinary sheathing is used under this lath, the building paper being placed between the two.

**Metal Lath.** — Metal lath is furnished in a great variety of forms as listed in the classification at the beginning of this article. All metal lath is furnished either painted or galvanized. It is fireproof, and plaster applied over metal lath is less likely to crack than if applied over wood lath. All metal lath, except wire lath, is made in sheets 8, 10, or 12 ft. in length and of varying width. It is shipped in bundles containing several sheets. Metal lath is nailed to wood studding or furring strips and is wired to metal supports. Wire lath is furnished in rolls.

Expanded metal is formed by cutting sheet metal in such a way that it may be pulled out or expanded to cover a much larger area than that of the original sheet metal, as shown in Fig. 118. Expanded metal lath is used where the supports are close together. Diamond and rectangular mesh are satisfactory for a 16-in. spacing in side walls and 12-in. on ceilings, whereas ribbed lath may be used for considerably greater spacings, the spacing depending upon the type of lath.

Integral lath is so designed that it does not require studding for support. It is used chiefly in solid partitions.

Sheet-metal lath is not expanded but is punched in such a manner that the plaster when applied can secure a firm grip on the lath.

Wire lath may be woven or welded; it has a mesh $\frac{3}{8}$ in. to $\frac{1}{2}$ in. square, and may be obtained with stiffeners or without stiffeners, as shown in Fig. 118. These stiffeners are V-shaped metal or round rods and are spaced 8 in. apart. Lath without stiffeners may be used on studding spaced 12 in. and in some cases 16 in. but for greater spacings stiffeners are required. When the lath is applied over wood sheathing or other flat surfaces, the stiffeners act as furring strips to hold the lath away from the flat surfaces and enable the plaster to form a key. When used over

wood sheathing for exterior surfaces a waterproof paper is placed between the sheathing and the lath.

Plaster board consists of a gypsum plaster core and surfaces of fibrous felt sheets pressed together in sheets $\frac{1}{4}$ in., $\frac{5}{16}$ in., $\frac{3}{8}$ in. and $\frac{1}{2}$ in. in thickness and 32 in. wide by 36 in. long. It is used as a substitute for wood and metal lath and is nailed to wood studding or furring strips spaced 12 in. or 16 in. It can be sawed to any desired size. Gypsum plaster adheres very satisfactorily to the surface of plaster board. Plaster board is fire-resistant and is cheaper than metal lath. Its use is confined to interior surfaces.

Fiber board is made of cane fiber, straw, or similar fibrous materials pressed into sheets 4 ft. wide and about $\frac{1}{2}$ in. thick. Lengths up to 12 ft. are available. In addition to serving as plaster bases, these materials have considerable resistance to the passage of heat and sound. They are very useful as heat insulators when placed on the ceiling of the top story of buildings and for rooms in the attics of residences.

## ARTICLE 80. PLASTER AND STUCCO SURFACES

**Classification of Materials.** — The cementing materials commonly used for plaster surfaces are the gypsum plasters, lime, and portland cement, and those used for stucco surfaces are portland cement and magnesite stucco. Of these materials those most extensively used are the gypsum plasters for interior plastering and portland cement for stucco.

### Gypsum Plasters

**Classification.** — Gypsum plasters are available in a great variety of forms designed to meet the special requirements of the various uses to which such plasters are put. In preparing the following paragraphs the Standards of the American Society for Testing Materials have been extensively used. The process of manufacture of gypsum plasters is given in Article 5.

*Gypsum neat plaster* is a plastering material in which not less than 60.5 per cent of the cementitious material is calcined gypsum, $CaSO_4.\frac{1}{2}H_2O$, mixed at the mill with other materials to control the working quality, setting time, and the fibering. Gypsum neat plasters are furnished with hair fiber to serve as a binder for use, with sand, in scratch coats on wood and metal lath and plaster board, and without hair fiber for use in second or brown coats over scratch coats or for the first coat on masonry surfaces where a scratch coat is not required.

*Gypsum ready-sanded plaster* (prepared plaster) is a plastering material in which the predominating cementitious material is calcined gypsum,

and which is mixed at the mill with all the constituent parts, including sand, in their proper proportion. It requires only the addition of water to make it ready for use. The ready-sanded plaster for the scratch or first coat should contain not more than two-thirds by weight of sand. The other third consists of gypsum neat plaster. The ready-sanded plaster for the browning or second coat consists of not more than three-fourths parts by weight of sand and the remaining one-fourth part of gypsum neat plaster.

*Gypsum wood-fibered plaster* is a gypsum plaster in which wood fiber is used as an aggregate with gypsum neat plaster as the cementing material. For best results this plaster is used without sand and produces a light, tough, durable, sound-absorbing coating but it is commonly mixed with an equal amount by weight of sand. Wood-fibered plaster is often used for one-coat work.

*Bond plaster* is a plaster with high adhesive properties which is made especially for use as a first coat on interior concrete surfaces. It is a ready-mixed plaster which requires only the addition of water to be ready for use.

Several gypsum plasters are manufactured for use in finish coats. One of these is suitable for a white troweled finish, another for a gray troweled finish and another for a gray sand-float finish. These plasters contain no lime. *Gaging plaster* is prepared for use with lime putty to form a lime-putty finish, one part by volume of gaging plaster being mixed with three parts of lime putty immediately before use.

*Gypsum molding plaster* is a material consisting essentially of calcined gypsum for use in making interior embellishments, cornices, etc.

*Keene's cement* is anhydrous gypsum, the set of which is accelerated by the addition of other materials. It is harder, stronger, and more water-resistant than other gypsum plasters and is also more expensive.

Gypsum plasters are also called *hard-wall plasters, cement plasters,* and *patent plasters.*

The hair in the hair-fibered plasters is used to bind the material together until it has set. It is usually manila or jute fiber. Shredded wood fiber is used in wood-fibered plaster.

**Mixing.** — In mixing gypsum plaster, a clean tight box about 3 ft. wide and 6 ft. long raised about 4 in. at one end is used. This box should be thoroughly cleaned after mixing each batch and the tools should be kept clean because the presence of plaster which has set tends to hasten the setting of a new batch. For this reason the remains of an old batch should never be mixed with a new batch. Only the quantity which can be applied in one hour should be mixed at one time and mortar which has started to set should not be *retempered* by adding more water and remix-

ing. Tools should not be rinsed in the gaging water. The plaster and sand should be thoroughly mixed dry and placed in the high end of the box before adding water. The water should be added at the low end and the mixing should be done by pulling the plaster slowly into the water with a hoe, allowing it to soak a few minutes, and mixing thoroughly.

The sand used should consist of fine, granular material, containing not less than 80 per cent by weight of silica, feldspar, dolemite, magnesite or calcite, and should be free from saline, alkaline, organic, or other deleterious substances. It should be graded from fine to coarse.[1]

The water used for mixing should be fresh, pure and clean. The presence of excessive amounts of mineral or organic substances in the water may be harmful.

**Proportions.** — The mixture used for the scratch coat on wood and metal lath is one part, by weight, of fibered plaster to one and one-half or two parts of sand and that for the brown coat is one part, by weight, of plaster to two or three parts of sand. For application to brick and tile, two and one-half or three parts by weight of sand to one part of unfibered plaster may be used. Wood-fibered plaster is used without sand if its full advantages are to be secured or it may be mixed with one part of sand. Bond plaster should be used without sand for the best results. The ready-sanded plasters are ready for use without further additions. Lime putty finishes are mixed in the proportions of one part by volume of gaging plaster to three parts of lime putty. Sand float finish is obtained by a mixture of one part by weight of unfibered plaster and one part of sand which passes a No. 12 screen. The prepared finishes usually require no additions except water.

**Application.** — Wood lath should be thoroughly soaked several hours before plastering. If this is not done the lath will absorb water from the plaster and swell after the plaster is applied thereby causing lath cracks in the plastered surfaces. Masonry surfaces should be wetted a sufficient amount to reduce the suction to such an extent that they will not absorb the water which is necessary for the proper setting of the plaster but they must not be too wet or the plaster will not adhere to them. Plaster board should not be wetted.

The tools used in plastering are shown in Fig. 158*a*. The scratch coat over metal lath should be applied with a trowel using sufficient pressure to form a good key and should form a thin coat over the lath. Too much pressure will cause a waste of material by causing it to drop off behind the lath. This coat is scratched or roughened before it has set to form a

[1] For detailed specifications for Gypsum Plastering Sand see A. S. T. M. Standards.

better surface for the bonding of the brown coat. A scratch coat is not necessary on masonry walls but crooked and uneven walls should be straightened by filling in the low places with mortar before the brown coat is applied. The brown coat should be applied after the first coat has set hard but before it is dry. Considerable pressure should be used in applying this coat and the surface should be straightened with rod and darby leaving it roughened ready to receive the finish coat. The brown coat should be kept back from the face of the grounds to allow for the finish coat. After the brown coat has dried it is sprinkled lightly and then the finish coat is applied. If a *lime-putty finish* is to be used it is applied in a coat about $\frac{1}{8}$ in. in thickness and troweled to a glazed finish with a steel trowel the surface being kept moist during the process by applying water continuously with a brush. The *sand-float finish* is secured by going over the finish coat consisting of gypsum plaster and sand with a wood or cork float producing a finish which resembles coarse sandpaper. The *troweled finish* using gypsum finish plaster is worked in the same way as the lime-putty finish. Special finishes too numerous to mention may be obtained by using suitable materials and methods of application.

Plaster should be protected from drying out before setting processes have been completed but after set has taken place it should be dried out rapidly. In hot dry weather, it may be necessary to close all of the openings of the building whereas in cold or rainy weather heat and ventilation may be required. Plaster should be kept from freezing for at least twenty-four hours after application. The changes which occur during the setting of gypsum plasters are described in Article 5.

**Uses.** — Gypsum plasters are extensively used for interior plastering but they will not withstand long continued wetting so are not suitable for exterior use as stucco.

## Lime Plasters

**Classification.** — Lime for use in plastering is furnished in the form of lump lime, which is calcined limestone manufactured as described in Article 5, and hydrated lime, which is calcined lime to which a sufficient amount of water to form the hydroxide has been added at the place of manufacture. Hydrated lime is a fine white powder.

Lump lime is divided into two general classes: calcium lime which contains a small percentage of magnesium, and magnesium lime which contains a relatively high percentage of magnesium.

Hydrated lime is divided into two classes: *masons' hydrated lime*, which has a relatively low plasticity, and *finishing lime*, which has a high

plasticity. Either class is suitable for scratch and brown coats but only finishing lime is suitable for the finish coat.[1]

For a more detailed description of the classification of limes see Article 5.

**Slaking and Mixing.** — Lump lime is prepared for use by mixing with water to form lime putty or paste. This process is called *slaking* and results in the converting the oxides of calcium and magnesium, comprising the lime, into hydroxides. The volume of the lime more than doubles during the process and, in the case of calcium limes, a large amount of heat is generated.[2] Hydrated lime has been slaked at the factory. It is converted into a paste by mixing with water, the increase in volume being very small. For further discussion of the slaking of lime see Article 5.

After slaking, lime should be run through a sieve and then be allowed to age for a week or more to make certain that the slaking process is complete and to improve the plasticity and sand-carrying capacity of the lime. A No. 8 sieve should be used for lime to be used for scratch coats and brown coats and a No. 10 sieve for lime for finishing coats. Sand may be added before or after the putty has aged. Hydrated lime should be allowed to stand for at least twenty four hours before using.

If lime is used before the slaking process has been entirely completed, the unslaked portions will slake after the plaster has been applied. The expansion which accompanies slaking will break out little chips of plaster forming pits which are often called *lime pops*. Pitting may also be caused by the presence of small particles of overburned lime. Ageing usually prevents pitting from either cause.

Lime putty shrinks a large amount in setting and so cannot be used without mixing other materials with it to reduce this shrinkage. For scratch coats and brown coats sand is used for this purpose and also to reduce the cost. For the finish coat, fine white sand is used or, if a hard, highly polished surface is desired, plaster of paris or gaging plaster may be used.

The sand for lime plaster should consist of hard, strong, durable, uncoated mineral or rock particles, free from injurious amounts of saline, alkaline, organic or other deleterious substances. Not more than 10 per cent of the sand should be retained on a No. 8 sieve and it should be uniformly graded from fine to coarse.[3]

[1] For specifications for Quicklime and Hydrated Lime for Structural Purposes see the A. S. T. M. Standards.

[2] For method of preparation of lime putty see A. S. T. M. Standards.

[3] For detailed specifications for sand for use in lime plaster see A. S. T. M. Tentative Standards for 1927.

In order to give the plaster sufficient strength, particularly while setting is under way, it is necessary to mix hair or fiber in the scratch coat and preferably in the brown coat. The hair should be clean, long, goat or cattle hair free from grease and should be well whipped and soaked before using. Vegetable fiber in place of hair should be well whipped and at least 2 in. long. The hair is worked into the mortar after the slaking of the lime has been completed but before ageing. If the hair is added before the slaking is completed it may become brittle and worthless due to the heat generated during the slaking.

Mortar may be mixed by hand but machine mixing gives better results. An ordinary concrete mixer may be used but machines especially designed for mortar mixing are preferable.

The time of set of lime mortar may be hastened and the strength increased by the addition of small amounts of portland cement or Keene's cement. The amounts to be added are determined by the desired time of set and strength. If only the hastening of the set is desired, gypsum plaster may be used.

**Proportions.** — For convenience, lime plaster is usually proportioned by volume instead of by weight. The proportions are expressed in terms of the proportions of lime paste or putty and sand. This putty may be made by slaking lump lime or from hydrated lime. About 27 lb. of quicklime or about 44 lb. of hydrated lime will make one cubic foot of stiff putty. The sand-carrying capacity of various limes differs greatly, so any proportions which might be given must be quite approximate. If too little sand is used, the material cost for the mortar is high and the mortar is sticky. If too much sand is used, the cost of materials is low but the labor cost of mixing and spreading is high and the plaster is not durable.

The proportions commonly used for the scratch and the brown coats are:

*Scratch coat:* One part stiff lime putty to 2 or $2\frac{1}{2}$ parts of sand by volume.

*Brown coat:* One part of stiff lime putty to 3 or 4 parts of sand by volume.

The amount of hair or fiber in the scratch coat should be about one bushel per cubic yard of sand. If hair is used in the brown coat, one-half bushel per cubic yard should be sufficient. More sand is used in the brown coat than in the scratch coat to reduce shrinkage cracks.

The proportions used for the different kinds of finish coats are:

*White coat:* Three parts of stiff lime putty to 1 part of plaster of paris.

*White sand finish:* Three parts of stiff lime putty, 3 parts of white sand, 1 part of plaster of paris.

*Brown sand finish:* One part stiff lime putty, 3 parts of brown sand, small amount of plaster of paris.

**Application.** — The method of application of lime plaster is about the same as that of gypsum plaster described earlier in this article. Some difference is caused by the fact that lime mortar is much slower in setting than gypsum mortar. The chemical change which occurs during setting requires carbon dioxide, which is absorbed from the air. In order that this setting action may be completed it is necessary to postpone the painting of lime plaster surfaces with oil paint until sufficient time has been allowed for setting. If the plaster is applied to lath the absorption may proceed from the unfinished side but if applied to a solid base at least two months should be allowed before oil paint is applied.

When the scratch coat is firm but not dry, the surface should be scratched with a metal scratcher or a broom to insure a good bond with the brown coat. The brown coat is applied when the scratch coat is dry. It is brought to a true surface by the use of the rod and darby and when this coat is firm but not dry it should be rubbed with a float to eliminate shrinkage cracks and to prepare the surface to receive the finish coat. The finish coat is applied when the brown coat is dry.

The fumes given off by salamanders are injurious to lime, so the use of salamanders should not be permitted.

## Special Plasters

Plasters of various compositions may be applied in various ways so as to imitate natural stones. The more common of these are scagliola, which is an imitation marble; imitation caen stone, which is made to resemble the natural caen stone found in France; imitation travertine, which resembles the ornamental limestone of that name. False joints are cut in the imitation caen stone and travertine and filled with Keene's cement so as to give the effect of stone masonry.

## Portland Cement Stucco

The following instructions concerning portland cement stucco have been taken from the Recommended Practice for Portland Cement Stucco adopted by the American Concrete Institute. For a complete statement of this Recommended Practice see Vol. 19 of the Proceedings of the American Concrete Institute.

I. **General.** — *Design.* — Whenever the design of the structure permits, an overhanging roof or similar projection is recommended to afford protection to the stucco. Stuccoed copings, cornices and other exposed horizontal surfaces should be avoided whenever possible. All exposed stuccoed surfaces should shed water

quickly, and whenever departure from the vertical is necessary, as at water tables, belt courses, and the like, the greatest possible slope should be detailed. Stucco should not be run to the ground whenever other treatment is possible. Should the design of the structure require this treatment, the backing should be of tile, brick, stone, or concrete, providing good mechanical bond for the stucco, and should be thoroughly cleaned before plastering. Unless special care is taken to thoroughly clean the base and each plaster coat from dirt and splash before the succeeding coat is applied, failure of the stucco may be expected.

*Flashing.* — Suitable flashing should be provided over all door and window openings wherever projecting wood trim occurs. Wall copings, cornices, rails, chimney caps, etc., should be built of concrete, stone, terra cotta, or metal with ample overhanging drip groove or lip, and watertight joints. If copings are set in blocks with mortar joints, continuous flashing should extend across the wall below the coping and project beyond and form an inconspicuous lip over the upper edge of the stucco. Continuous flashing with similar projecting lip should be provided under brick sills. This flashing should be so installed as to insure absolute protection against interior leakage. Cornices set with mortar joints should be provided with flashing over the top. Sills should project well from the face of the stucco and be provided with drip grooves or flashing as described above for brick sills. Sills should also be provided with stools or jamb seats to insure wash of water over the face and not over the ends. Special attention should be given to the design of gutters and downspouts at returns of porch roofs where overflow will result in discoloration and cracking. The end joints should be thoroughly protected with sheet-lead flashings. A 2-in. strip should be provided at the intersection of walls and sloping roofs and flashing extended up and over it, the stucco being brought down to the top of the strip. Double flashing should be used at the intersection of sloping roof with metal lath wall. The metal lath should be stapled into the upper or cap flashing at its upper edge which is rigidly attached to the wall behind. A fundamental rule in the design of a stucco structure is "keep water from getting behind the stucco."

*Preparation of Original Surface.* — (*a*) All roof gutters should be fixed, and downspout hangers and all other fixed supports should be put in place before the plastering is done, in order to avoid breaks in the stucco.

(*b*) Metal lath and wood lath should be stopped not less than 6 in. above grade to be free from ground moisture.

II. **Materials.** — *Cement.* — The cement should meet the requirements of the standard specifications for portland cement of the American Society for Testing Materials adopted by this Institute.

*Fine Aggregate.* — Fine aggregate should consist of sand, or screenings from crushed stone or crushed pebbles, graded from fine to coarse, passing when dry a No. 8 screen. Fine aggregates should preferably be of siliceous materials, clean, coarse, and free from loam, vegetable, or other deleterious matter.

*Hydrated Lime.* — Hydrated lime should meet the requirements of the standard specifications for hydrated lime of the American Society for Testing Materials.

*Hair or Fiber.* — There should be used only first quality long hair, free from foreign matter, or a long fiber well combed out.

*Coloring Matter.* — Only mineral colors should be used which are not affected by lime, portland cement, or other ingredients of the mortar, or the weather.

*Water.* — Water should be clean, free from oil, acid, strong alkali or vegetable matter.

*Lath.* — (*a*) Metal lath should be galvanized or painted expanded lath weighing not less than 3.4 lb. per sq. yd.

(*b*) Wire lath should be galvanized or painted woven wire lath, not lighter than 19-gage, 2½ meshes to the inch, with stiffeners at 8-in. centers.

(*c*) Wood lath should be standard quality, narrow plaster lath 4 ft. long and not less than ⅜ in. thick. (The use of wood lath is not recommended.)

III. **Design.** — *Tile.* — Tile for exterior walls should preferably be not less than 8 in. thick, and should be hard-burned, with dove-tail or heavy ragged scoring. Tile should be set in cement mortar. Joints should not be raked, but mortar should be cut back to surface. Neither wire mesh nor waterproofing of any type should be applied to tile walls before plastering, nor should any wooden members (except inserts for nailing) be embedded in masonry walls, particularly where they are to be covered with stucco.

*Brick.* — Surface brick should be rough, hard-burned, commonly known as arch brick. Brick should be set in cement mortar with joints not less than ⅜ in. thick, and the mortar should be raked out for at least ½ in. from the face.

*Concrete.* — Monolithic concrete walls should preferably be rough and of coarse texture, rather than smooth and dense, for the application of stucco. Walls of this type should be cleaned and roughened, if necessary, by hacking, wire brushing, or other effective means.

*Wetting.* — Before applying the stucco to tile, brick or concrete the surface should be brushed free from all dust, dirt and loose particles, and should be wetted to such a degree that water will not be rapidly absorbed from the plaster, but not to such a degree that water will remain standing on the surface when the plaster is applied.

*Frame Walls.* — (For the construction of frame walls to receive stucco see Article 28.)

IV. **Construction.** — *Application of Lath,* (*a*) Metal Lath. — Lath should be placed horizontally, driving galvanized staples 1¼-in. by 14-gage not more than 8 in. apart over the furring or stiffeners. Vertical laps should occur at supports and should be fastened with staples not more than 4 in. apart. Horizontal joints should be locked or butted and tightly laced or properly tied with 18-gage galvanized wire.

(*b*) Wood Lath. — Lath should be placed horizontally on the furring with ½-in. openings between them. Joints should be broken every twelfth lath. Each lath should be nailed at each furring with 4d nails.

*Corners.* (*a*) Metal Lath. — The sheets of metal lath should be folded around the corners a distance of at least 3 in. and stapled down, as applied. The use of corner bead is not recommended.

(*b*) Wood Lath. — At all corners a 10-in. strip of galvanized or painted metal lath should be firmly stapled over the lath with 1¼-in. by 14-gage galvanized staples.

*Spraying.* — Before applying the first coat of plaster, wood lath should be thoroughly wetted, but water should not remain standing on the surface of the lath when the plaster is applied.

*Mixing.* — The ingredients of the mortar should be mixed until thoroughly distributed, and the mass is uniform in color and homogeneous.

*Retempering.* — Mortar which has begun to stiffen or take on its initial set should not be used.

*Consistency.* — Only sufficient water should be used to produce a good workable consistency. The less water the better the quality of the mortar, within working limits.

*Mortar.* — All coats should contain not less than 3 cu. ft. of fine aggregate to 1 sack of portland cement. If hydrated lime is used it should not be in excess of one-fifth the volume of cement. Hair or fiber should be used in the scratch coat only on wood lath, on metal or wire lath that is to be back-plastered, or on metal or wire lath which is applied over sheathing and is separated therefrom by furring deeper than $\frac{3}{8}$ in.

*Application.* — (*a*) The plastering should be carried on continually in one general direction without allowing the plaster to dry at the edge. If it is impossible to work the full width of the wall at one time, the joining should be at some natural division of the surface, such as a window or door.

(*b*) The first coat should thoroughly cover the base on which it is applied and be well troweled to insure the best obtainable bond. Before the coat has set it should be heavily cross-scratched with a saw-toothed metal paddle or other suitable device to provide a strong mechanical key.

(*c*) The second coat should be applied whenever possible on the day following the application of the scratch coat. The first coat should be dampened if necessary, but not saturated, before the second coat is applied. The second coat should be brought to a true and even surface by screeding at intervals not exceeding 5 ft., and by constant use of a straightening rod. When the second coat has stiffened sufficiently, it should be dry-floated with a wood float and lightly and evenly cross-scratched to form a good mechanical bond for the finish coat. The day following the application of the second coat, and for not less than three days thereafter, the coat should be sprayed or wetted at frequent intervals and kept from drying out.

(*d*) In back-plastered construction the backing coat should preferably be applied directly following the completion of the brown coat. The keys of the scratch coat should first be thoroughly dampened, and the backing coat then well troweled on to insure filling the spaces between the keys and thoroughly covering the back of the lath. The backing coat should provide a total thickness of plaster back of the lath of $\frac{5}{8}$ in. or $\frac{3}{4}$ in., and should finish about $\frac{1}{4}$ in. back of the face of the studs.

(*e*) The finish coat should be applied not less than a week after the application of the second coat. Methods of application will hereinafter be described under "finish."

*Two-Coat Work.* — Whenever two-coat work is required, the first coat should preferably be "doubled" — that is, as soon as the first coat is stiff enough it

should be followed by a second application of mortar, and this should then be treated as described for the second coat under paragraph (*c*). The finish should be applied not less than a week after the application of the first coat.

*Drying Out.* — The finish coat should not be permited to dry out rapidly, and adequate precaution should be taken, either by sprinkling frequently after the mortar is set hard enough to permit it, or by hanging wet burlap or similar material over the surface.

*Freezing.* — Stucco should not be applied when the temperature is below 32 deg. fahr., nor under any conditions such that ice or frost may form on the surface of the wall.

**Finish.** — *Stippled Finish.* — The finishing coat should be troweled smooth with a metal trowel with as little rubbing as possible, and then should be lightly patted with a brush of broom straw to give an even stippled surface.

*Sand-Floated Finish.* — The finishing coat, after being brought to a smooth, even surface, should be rubbed with a circular motion of a wood float with the addition of a little sand to roughen the surface slightly.

*Sand-Sprayed Finish.* — After the finishing coat has been brought to an even surface, it should be sprayed by means of a wide, long-fiber brush — a whisk broom does very well — dipped into a creamy mixture of one part of cement to two or three parts sand, mixed fresh at least every 30 minutes, and kept well stirred. This coating should be thrown forcibly against the surface to be finished. This treatment should be applied while the finishing coat is still moist and before it has attained its early hardening — that is, within 3 to 5 hours. To obtain lighter shades add hydrated lime not to exceed 10 per cent of the weight of the cement.

*Rough-cast or Spatter Dash.* — After the finishing coat has been brought to a smooth, even surface with a wooden float and before finally hardened, it should be uniformly coated with a mixture of one sack of cement to 3 cu. ft. of fine aggregate thrown forcibly against it to produce a rough surface of uniform texture when viewed from a distance of 20 ft. Special care should be taken to prevent the rapid drying out of this finish by thorough wetting down at intervals after the stucco has hardened sufficiently to prevent injury.

*Applied Aggregate.* — After the finishing coat has been brought to a smooth, even surface, and before it has begun to harden, clean round pebbles, or other material as selected, not smaller than ¼ in. or larger than ¾ in. and previously wetted, should be thrown forcibly against the wall so as to embed themselves in the fresh mortar. They should be distributed uniformly over the mortar with a clean wood trowel, but no rubbing of the surface should be done after the pebbles are embedded.

*Exposed Aggregate.* — The finishing coat should be composed of an approved selected coarse sand, crushed marble, or granite or other special material, in the proportion given for finishing coats, and within 24 hours after being applied and troweled to an even surface should be scrubbed with a stiff brush and water. In case the stucco is too hard, a solution of one part hydrochloric acid in four parts of water by volume can be used in place of water. After the aggregate particles

have been uniformly exposed by scrubbing, particular care should be taken to remove all traces of the acid by thorough spraying with water from a hose.

*Mortar Colors.* — When it is required that any of the above finishes should be made with colored mortar not more than 10 per cent of the weight of portland cement should be added to the mortar in the form of finely ground mineral coloring matter.

## Magnesite Stucco

**Composition and Manufacture.** — Magnesite stucco consists of a dry mixture of magnesium oxide, asbestos or other inert material, and a mineral pigment to which liquid magnesium chloride is added on the job to form a plastic material which may be applied as a plaster to wood and metal lath or to brick, hollow tile, and other masonry surfaces except gypsum blocks. When the magnesium chloride is added to the magnesium oxide, magnesium-oxy-chloride is formed. This is a very effective cementing material.

Magnesium oxide is prepared by calcining magnesite, which is magnesium carbonate, carbon dioxide being driven off during the process. Magnesium chloride in the powdered form may be included with the other dry materials so that it is only necessary to add water to make magnesite stucco ready for use. Various brands of magnesite stucco are on the market.

**Properties and Uses.** — Magnesite stucco is a satisfactory material for exterior use if properly applied and protected from excessive action of the weather. It has a low coefficient of expansion, so is not materially affected by temperature changes; it is quite elastic and will not crack readily; and since it will freeze only at very low temperatures it may be applied in cold weather. There is some possibility of the stucco acting on unprotected metal lath, therefore wood lath or galvanized metal lath should be used. Surface finishes of various textures and colors can be obtained with magnesite stucco. Many of the comments made under the heading of Portland Cement Stucco apply also to Magnesite Stucco.

## Ornamental Plastering

Ornamental plastering includes moldings, cornices, panels, decorative ceilings rosettes, etc., made of plaster or similar material and placed in the interior of buildings.

The base for moldings of small projection is built up solid with the same material as that used for the brown coat. It is built up to approximately the shape of the molding, making sure that there is clearance enough to allow for the finish coat, which is composed of lime putty gaged with plaster of paris. The finish coat is applied to this base and

is cut to the desired profile by means of a sheet-metal templet operating on guides. The finish coat cannot be cut with sharp outlines in one operation but must be gone over several times, the low places being filled in with mortar each time.

For larger moldings the base is built up of metal lath supported on braces.

The moldings and similar ornamental plastering are placed before the finish coat on the remainder of the walls and ceiling because the guides could not be placed on the finish coat of the walls and ceiling without marring it. Parts of moldings such as internal and external miters which cannot be run with templets must be formed by hand, or they may be cast and placed in position before the moldings are run. Parts of moldings such as dentils and brackets may be cast separately and "stuck" in place after moldings are run.

Ornaments which cannot be run are cast in gelatine molds, or they may be purchased from firms which make a specialty of this kind of work. They are made of plaster of paris or of a special mixture consisting of such materials as whiting, glue, paper pulp, and wood fiber. Such ornaments are "stuck" in place by means of plaster of paris.

## CHAPTER XV

# PAINTS AND OTHER PROTECTIVE COVERINGS

### ARTICLE 81. DEFINITIONS AND GENERAL DISCUSSION

Paint, varnish, enamel and lacquer are materials applied in the liquid form to the surface of wood, metal, brick or other materials, to form a thin coating or film which solidifies. This coating is applied for one or more of the following reasons: To protect from the elements and from wear; to improve the appearance and give the desired color and finish; to facilitate cleaning; or to improve the lighting of interiors of buildings. Stains are applied to wood surfaces to produce the desired color, to emphasize the grain, or to protect the wood. Metal surfaces may also be galvanized, sherardized, tin-plated, terne-plated, or nickel-plated for the purpose of protection or to improve their appearance.

Paint is a mixture of a vehicle and a pigment. The *vehicle* is the liquid portion of the paint and the *pigment* consists of solid particles added to give color and durability to the paint. Oil paints usually have linseed oil as the principal constituent of the vehicles but a *volatile thinner* such as turpentine is added to make the paint spread more readily and a *drier* is added to accelerate drying. During the process of drying, practically all of the turpentine evaporates, and little of it appears in the resultant product; the linseed oil becomes oxidized and hardens, binding the pigment together; and the pigment remains practically inert although some pigments act as driers.

Water paints consist of a solid material such as slaked lime or whiting to which water is added forming a liquid mixture which can be applied to a surface with a brush. The mixture of lime and water is known as *whitewash* and that of whiting and water, as *calcimine.* Other materials may be added to increase the adhesion of whitewash and in the case of calcimine these materials must be added because whiting itself will not adhere to a surface. Calcimine hardens simply by the evaporation of the water but the calcium hydroxide of whitewash absorbs carbon dioxide from the air and forms calcium carbonate.

There are two main classes of varnish, the distinction between the two being largely in the vehicle. The two classes are oil varnish and spirit varnish.

*Oil varnish* consists of resin and a drying oil such as linseed oil or chinese wood oil which is thinned with a volatile liquid such as turpentine to

which a drier has been added. Varnish dries by the evaporation of the thinner and the oxidation of the linseed oil, leaving a hard coating consisting of the resin and oxidized oil. Varnish is transparent and, since no pigment is used, it has the clear amber color given by the oil and resin. Some varnishes are practically colorless.

*Spirit varnish* consists of resin dissolved in some volatile oil which evaporates after the varnish is spread, leaving a coating of resin only.

*Enamels* are paints with varnish as a vehicle and various pigments to give the desired color.

*Lacquers* usually consist of a nitro-cellulose base to which certain gums, solvents, and pigments have been added.

*Wood stains* consist of a coloring material and a liquid which is composed of a drying oil and a thinner such as linseed oil and turpentine in the case of oil stains, water in the case of water stains, and alcohol in the case of spirit stains. The primary functions of stains are to color wood and to emphasize the grain.

The surface of paint may have a gloss finish, a semi-gloss or eggshell finish, or a flat, matte, or dull finish, depending largely upon the relative amounts of oil and turpentine used in the vehicle. Most pigments have no gloss and if mixed with turpentine, which simply evaporates, they will form a coating without gloss. However, some drying oil such as linseed oil must be used as a binder and linseed oil dries with a glossy finish, so the amount of gloss depends upon the amount of linseed oil present. If a high gloss is desired one part of turpentine to four parts of oil might be used but if a flat finish is desired the proportions would be about one part of oil to three parts of turpentine. Benzene has the same effect as turpentine.

Varnishes naturally dry with a gloss finish and since enamels have varnish as a vehicle they also dry with a gloss finish. Flatting varnishes have a dull finish generally due to wax incorporated in the varnish. Tung oil which has not been heated to too high a temperature dries flat and may be used in place of linseed oil in flattening varnish. The gloss finish may be removed from varnish by rubbing with powdered pumice stone and water after it has hardened.

Paint may be prepared by a painter from the raw materials or it may be obtained *ready mixed* or *prepared* ready for use. If a painter is to do the mixing, linseed oil paint of any color is usually prepared by first making a white paint and then securing the desired color by adding the proper coloring pigments. Nearly all pigments are furnished in paste form ground in linseed oil. The white paint is usually made by *breaking up* white-lead paste and zinc-oxide paste separately by adding linseed oil and working and stirring each with a wooden paddle forming a thick

liquid of uniform consistency. The zinc oxide is then added to the white lead in the proper proportions. To this mixture is added the color pigment which has been broken up in oil. The drier is added, then the remainder of the oil, and finally the turpentine, with continual stirring during the entire process.

Varnish and enamel are furnished ready for use by the manufacturers and should not be altered in composition by the painter.

Paints having water as a vehicle are often referred to as *distemper paints*.

Paint and varnish are usually applied with a bristle brush but the air spray is coming into extensive use. Small articles may be coated by dipping into vats containing paint.

**Terms Relating to Paint Specifications.** — The following definitions have been adopted by the American Society for Testing Materials and appear in the 1927 Standards:

*Paint.* — A mixture of pigment with vehicle, intended to be spread in thin coats for decoration or protection, or both.

*Varnish.* — A liquid coating material, containing no pigment, which flows out to a smooth coat when applied and dries to a smooth glossy, relatively hard, permanent solid when exposed in a thin film to the air. Some materials possessing the other characteristics dry without the usual gloss and are termed *flat varnish.*

According to the definition of paint, a mixture of pigment and varnish is a paint, and on the other hand a solution of stain in oil or varnish, no pigment being present, is not a paint.

*Enamel.* — A special kind of paint which flows out to a smooth coat when applied and dries to a smooth, glossy, relatively hard, permanent solid when exposed in a thin film to the air. An enamel always contains pigment and has a considerable hiding power and color. Some enamels dry to a flat or eggshell finish instead of a gloss finish.

*Pigment.* — The fine solid particles used in the preparation of paint, and substantially insoluble in the vehicle. Asphaltic materials are not pigments except when they contain substances substantially insoluble in the vehicle in which they are used.

*Vehicle.* — The liquid portion of a paint. Here anything that is dissolved in the liquid portion of a paint is a part of the vehicle.

*Volatile Thinner.* — All that liquid portion of a paint, water excepted, which is volatile in a current of steam at atmospheric pressure.

*Non-volatile Vehicle.* — The liquid portion of a paint excepting its volatile thinner and water.

*Drying Oil.* — An oil which possesses to a market degree the property of readily taking up oxygen from the air and changing to a relatively hard, tough, elastic substance when exposed in a thin film to the air.

*Drier.* — A material containing metallic compounds added to paints and painting materials for the purpose of accelerating drying.

*Size.* — In the painting art, a liquid coating material, intended to close the pores, used to prepare a surface for further treatment. It is not regarded as a finishing material.

*Filler.* — A special kind of paint used for filling pores or other small breaks in the continuity of a surface to render it smooth preparatory to further treatment. When applied and exposed to the air, a filler should dry to a relatively hard, permanent solid capable of properly supporting subsequent coats.

*Covering Power.* — The use of this term should be avoided if possible. This term has been used so loosely that it might mean hiding power, spreading power or the simple property of producing a coat.

*Hiding Power.* — The power of a paint or paint material as used to obscure a surface painted with it. In this definition the word *obscure* means to render invisible or to cover up a surface so that it cannot be seen.

*Spreading Rate.* — The rate at which a paint material, as used, is brushed out to a continuous uniform film expressed in terms of the area to which a unit volume, as used, is applied. This term must not be confused with the much abused term *spreading power.* The use of the term spreading rate is illustrated in the following sentence: "The paint when spread on a planished iron surface at the rate of 600 sq. ft. to the gallon will not sag or run when placed in a vertical position at 70 deg. fahr."

Other terms included in these Standard Definitions are: Standard, Equal to, Pure, Commercially Pure, Adulteration, Adultrant, Opacity, Fineness, Crystallin, Amorphous, Toner, Lake, Semi-drying Oil, Non-drying Oil, Tinting Strength, Color, Tint, Shade, Hue, Tone, Drying, Specific Gravity, Density, Gallon, Water, and Dry.

## REFERENCES

The following references were of considerable assistance in preparing this chapter:

Circular 69 of the Bureau of Standards, entitled Paint and Varnish. Painting and Decorating, produced under the direction of The International Association of Master House Painters and Decorators, by F. N. Vanderwalker.

## ARTICLE 82. DRYING OILS, VOLATILE THINNERS, AND DRIERS

The terms drying oil, volatile thinner, and drier have been defined in the previous article.

## Drying Oils

The most important drying oil used in paint and varnish manufacture is linseed oil, but chinese wood oil or tung oil is quite extensively used and its use is increasing. Drying oils of minor importance are poppy-seed oil, soya-bean oil, fish oil, and rosin oil.

**Linseed Oil.** — Linseed oil is made by pressing crushed or ground flaxseed (linseed) without heating as in the *cold-pressed process;* by pressing ground flaxseed which have been heated to a temperature of 160 to 180 deg. fahr. as in the *hot-pressed process;* by forcing the ground flaxseed against a conical grating by means of a screw, the oil passing through the grating and the pressed meal coming out of the end of the grating as in the *continuous-expeller method;* or by extracting the oil from the ground flaxseed by leaching with petroleum naphtha and then distilling the naphtha from the oil as in the *extraction process.* The hot-pressed oil is the most extensively used. The oil produced by those processes is filtered and allowed to stand in order that *foots,* which causes it to be cloudy, may settle out. When raw oil is heated above 350 deg. fahr. it may thicken and become cloudy and is said to *break.* This tendency may be overcome by allowing the oil to age by standing for a long period or by refining. Oil which is used in varnish manufacture must not break.

The drying of linseed oil is not due to evaporation of the oil but primarily to the absorption of oxygen from the atmosphere. This oxidation may be hastened by heating the oil to 350 deg. fahr. or higher and then cooling, by the addition to the oil of certain materials known as driers, or by a combination of these two methods which produces what is called *boiled oil* although the oil does not actually boil in the process. The driers commonly used consist of linoleates, resinates, or borates of lead and manganese made as described under the heading of driers. Linseed oil which has dried or oxidized is known as *linoxyn.* It is a relatively hard, tough, elastic substance. The drying of a film of raw oil requires several days but boiled oil will dry in less than a day under proper conditions. Boiled oil is inferior to raw oil in durability, elasticity, and penetrating power and since it is darker than raw oil it is not as satisfactory as raw oil for use as a vehicle for white or light-colored paints.

Raw linseed oil to which driers have been added without heating is known as *bung hole oil* and is an inferior product.

The color of linseed oil varies from pale yellow to amber and often has a tinge of green or red. The color of the darker oils may be cleared up considerably by exposing to sunlight or by a bleaching process which consists of adding sulphuric acid to the oil and blowing air through it at the same time. Certain impurities gradually settle to the bottom and

after the oil is washed with water to remove the sulphuric acid, and filtered it is much paler in color and is known as *bleached oil.* The use of bleached oils for light-colored or white paints on exterior work exposed to sunlight is of questionable value since the sunlight soon bleaches the paints made with the unbleached oil so that these are as light as the paints made from bleached oil. Bleached oil is not as durable as ordinary oil and is more expensive.

**Chinese Wood Oil.** — Chinese wood oil is also known as *china wood oil* or *tung oil.* It is made by pressing the nuts of the tung tree found in China. Raw tung oil dries very rapidly forming an opaque wax-like inelastic film and so is not suitable for use in paint and varnish. By heating the oil and adding suitable materials these objectionable properties are overcome, the treated oil forming a film which is glossy and more durable, more resistant to wear, more impervious to water but less elastic than the linseed oil film. The treated oil dries more slowly than the raw oil. Tung oil is extensively used with linseed oil. It is used in the manufacture of varnish and enamel. Cement floor paint is commonly made of chinese wood oil and a hard resin.

**Other Drying Oils.** — *Poppy-seed oil* is a clear, colorless oil made from poppy seeds. It is very desirable for use in the lighter-colored paints but due to its high cost it is used only for artists' colors.

*Soya-bean oil* produced by pressure from the soya bean is a drying oil which is not used alone but is used with linseed oil as an adultrant to reduce the cost. *Fish oil* or *menhaden oil* is obtained from the menhaden fish by boiling or by pressure. When treated with a suitable drier it makes a satisfactory drying oil which is quite resistant to weathering and to the action of heat. It has an objectionable odor and cannot be used indoors.

## Driers

Driers are materials containing metallic compounds added to paints and painting materials for the purpose of accelerating drying. They usually consist of the linoleates, resinates, or tungates of lead and manganese. These are organic compounds produced by adding lead and manganese salts to hot linseed oil, resin, or tung oil respectively and thinning with turpentine or benzene. Driers produced in this way are called *Japan driers* or *Japans.* A drier when added to a drying oil acts as a medium for the transference of oxygen from the atmosphere to the oil thus causing the oil to harden. Unfortunately, driers do not cease to act after the oil has dried but may cause oxidation to continue until the film has been destroyed.

Oil driers are inorganic compounds used only as driers for linseed oil.

The oil driers commonly used are litharge and red lead or minium, which are oxides of lead, lead borate, lead acetate, and manganese dioxide. These driers may be added to cold oil as in bung hole boiled oil, but to give good results the mixture of the oil and drier should be heated thus producing boiled oil.

### Volatile Thinners and Solvents

**Turpentine.** — The principal thinner or solvent used in paint and varnish is turpentine. It is made chiefly by distilling balsam, which is the resin obtained from pine trees. The residue left after the turpentine has been distilled off is rosin. Turpentine obtained in this way from balsam is also called spirits of turpentine, oil of turpentine, sap turpentine and gum spirits. Wood turpentine is another product and is obtained by the distillation of scrap wood such as sawdust and tree stumps containing resin instead of the balsam from the living trees. Wood turpentine which has been refined is satisfactory for use in paint and varnish.

Turpentine is a clear volatile liquid the chief use of which is in thinning linseed-oil paint and varnish to facilitate spreading, to increase their ability to penetrate into the pores of wood, and to hasten drying. Turpentine is also used as the principal component of the vehicle of "flat" paints. Such paints dry without gloss and are used as a final coat over linseed oil paints. Sufficient linseed oil must be used in flat paints to bind the pigment but the quantity required for that purpose is small. Pure turpentine evaporates without leaving a residue but commercial turpentine leaves a slight deposit of resin.

**Turpentine Substitutes.** — Since the chief function of turpentine is to facilitate the application of paint and considering that it evaporates during the drying process, other volatile liquids which are less expensive are frequently substituted for turpentine. The most common of these are benzene, which is obtained from the distillation of certain petroleum oils; and benzol (benzene) and solvent naphtha, which are obtained from the distillation of coal tar.

**Other Volatile Thinners.** — Other volatile thinners are grain (ethyl) alcohol, denatured alcohol, and wood (methyl) alcohol, which are used in shellac varnishes; amylacetate (banana oil), which is used as a solvent for nitrated cotton in making nitrocellulose lacquers; and carbon bisulphide, which is used in some bituminous varnishes.

## ARTICLE 83. PIGMENTS

**Classification.**[1] — The various pigments in use may be roughly divided into (*a*) body pigments, that is, those which constitute the bulk of the pigment present and give to the paint film its characteristic prop-

[1] U. S. Bureau of Standards Circular 69, Paint and Varnish.

erties; (*b*) color pigments, which are used primarily to produce a decorative effect; and (*c*) extenders, that is, substances which have few, if any, of the properties required of body pigments but which on account of their cheapness are added to paints, in many cases without harmful effects. There is no sharp distinction between these classes since many color pigments serve to give both body and color to a paint. Many substances that may be classed as extenders were formerly considered solely as adulterants, although now it is recognized that, in some cases, at least, the use of certain extenders may improve the quality of a paint.

The white pigments are used in making white paint for use directly or as a base for colored paints which are given the desired color by adding the proper color pigments, but when very dark-colored paints are desired they are usually made directly from the color pigments. In making white paints, a white pigment or a combination of white pigments is mixed with linseed oil, a volatile thinner such as turpentine, and a drier.

## White Pigments

**Basic Carbonate White Lead, $2PbCO_3.Pb(OH)_2$.** — White lead is a body pigment in the form of a white powder but for convenience in use it is mixed with a small percentage of linseed oil by the manufacturers to form a thick paste.

White lead is manufactured by several processes, the oldest and most important being the *Old Dutch process.* In this process metallic lead in the form of perforated discs about 6 in. in diameter is placed in earthenware pots in the bottom of which, but not in contact with the lead, is placed acetic acid. These pots are stacked in tiers with a layer of tan bark between each tier. The tan bark gradually ferments, generating heat and giving off carbon dioxide gas. Under the action of this heat the acetic acid is vaporized and attacks the lead converting it into basic lead acetate. The carbon dioxide gas formed by the tan bark finds its way into the pots and converts the basic lead acetate into basic lead carbonate, which is white lead, and releases acetic acid for the further continuation of the process, which lasts about three months. The white lead thus formed is a flaky substance which is crushed, screened, washed, and ground in oil forming a paste which is ready for the market.

Other processes are the *Carter process* in which lead in the form of granular dust is treated with acetic acid forming the basic acetate which is converted to the basic carbonate by carbon dioxide; and the *precipitation process* in which lead is dissolved in acetic acid in the presence of air producing basic lead acetate, and the basic carbonate is precipitated from the acetate solution by carbon dioxide.

White lead when mixed with linseed oil forms a paint which hides well and has a good spreading power but is blackened by air containing compounds of sulphur and has a tendency to chalk or change to a powder. This tendency to chalk may be overcome by adding zinc oxide but since zinc white has a tendency to crack and chip care must be used in proportioning these materials. The surface of white-lead paint is softer than that of zinc-oxide paint and takes up dirt more readily. Other names by which basic carbonate white lead is known are corroded lead, corroded white lead, hydrate of lead, lead carbonate, hydrocarbonate of lead, and lead.

**Basic Sulphate White Lead, $(PbSO_4)_2.Pb(OH)_2$.** — Basic sulphate white lead is different in composition but similar in properties to basic carbonate white lead. It is not usually so white as the best basic carbonate but is not discolored to so great an extent by sulphur compounds present in the atmosphere. Specifications often permit the use of either the carbonate or the sulphate.

Basic sulphate white lead is made by oxidizing with air the fumes produced by roasting and vaporizing galena ore, which is lead sulphide, PbS. The white fumes thus formed are collected in large bags which permit the air and gas to escape through the meshes of the bag material and retain the basic sulphate white lead which is in the form of a white powder. Other names for basic sulphate white lead are sublimed lead, sublimed white lead, sulphate of lead, or white lead. This material must not be confused with sulphate of lead ($PbSO_4$) which is very inferior material.

**Zinc Oxide, ZnO.** — Zinc oxide or zinc white, a body pigment is a fine white powder but for convenience in use it is mixed with linseed oil by the manufacturers to form a paste.

In making *French process* zinc oxide, metallic zinc is vaporized by heating and the fumes thus formed are oxidized by the air producing a fine white powder which is deposited in long chambers. The particles of zinc oxide are deposited in the order of their size, the larger particles being deposited as the fumes enter the chambers and the smaller at the farther end. The finest particles are the whitest and are known as "white seal," the next are "green seal" and the coarsest are "red seal." *American process* zinc oxide is made by roasting the sulphide or carbonate ores of zinc and may not be as white as the French process zinc oxide. When mixed with linseed oil zinc oxide forms a paint which is very white, has a good hiding power and spreads well. It is not darkened by air containing sulphur compounds and if it were not for its tendency to crack it would make an ideal paint. This tendency to crack is avoided by mixing with white lead as has just been explained. Zinc oxide forms

a harder surface than white lead so does not get dirty as readily. It is used alone as the pigment in high-grade white enamels. Zinc oxide is also known as white zinc, and zinc.

**Lithopone.** — Lithopone is a white powder composed of barium sulphate and zinc sulphide made from the precipitate formed by adding a solution of barium sulphide to a solution of zinc sulphate. It is a body pigment. Paints made from lithopone will not stand outdoor exposure but may be successfully used indoors. Lithopone is the whitest pigment known and is extensively used in cheap enamels and in flat wall paints which dry without a gloss. Inferior grades turn gray in sunlight but change back to white in the dark. Lithopone reacts with white lead pigment to form black lead sulphide so these pigments are not used together.

**Barium Sulphate (Barytes and Blanc Fixe), $BaSO_4$.** — This is a widely-used extender formed either by grinding the natural mineral barytes or by precipitation by treating a solution of barium chloride with a solution of sodium sulphate. The natural sulphate is known as *barytes* and the precipitated sulphate as *blanc fixe* and *permanent white.*

Barium sulphate is an inert white material which has little hiding power when mixed with oil. It is used to dilute white and colored paints and many claim that it improves the quality of the paint when used in proper proportions.

The form obtained by precipitation is known as *lake base* for it is extensively used as a base on which colors are precipitated in forming the pigments called *lakes.*

**Magnesium Silicate (Asbestine).** — Magnesium silicate when used as a pigment is made by grinding asbestos and is known by the trade name of *Asbestine.* It is a white pigment, classed as an extender whose chief function is to prevent the settling out of other pigments when paint is left standing.

**Calcium Carbonate (Whiting) $CaCO_3$.** — The calcium carbonate used as a pigment is made by grinding and washing natural chalk, allowing it to settle, and then drying. It is graded according to fineness into Paris white, gilders' whiting, and commercial whiting. Paris white and gilders' whiting are very fine and are used to neutralize any acid which may develop in paint and to aid in holding the other pigments in suspension. Commercial whiting is used in the water paint known as calcimine and in making putty by mixing with linseed oil. Calcium carbonate may be made by treating lime water with carbon dioxide forming a precipitate. In this form it is used in making putty but not extensively as a pigment.

**Silica (Silex) $SiO_2$.** — Silica when used as an extender pigment is made by crushing and grinding white sand, flint, chert, etc. It is a

white, inert powder which gives "tooth" to paints but which has no hiding power. On account of its lack of hiding power it is used as a base for paste fillers for wood to form which it is mixed with a quick-drying varnish. Silica is found in the finely divided form as diatomaceous earth.

**Gypsum (Terra Alba) $CaSO_4.2H_2O$.** — Gypsum when used as an extender pigment is made by grinding gypsum rock. It has good hiding power when mixed with water vehicle so is used in calcimines and is also used to dilute oil paints. Gypsum which has been burned at a temperature sufficiently high to drive off all of the combined water is used as an extender in Venetian red pigment.

**China Clay or Kaolin (Hydrated Aluminum Silicate, Fuller's Earth).** — This is a very white amorphous powder produced by the weathering of feldspar. It has no hiding power and lacks tooth. It is used to prevent the settling of pigments in mixed paints and to improve the brushing quality. Kaolin is used as an inert base on which colors are precipitated in making the pigments known as lakes.

## Color Pigments

Usually the various colored paints are made by adding a color pigment to white paint. Very dark paints, however, are made directly from the color pigments, linseed oil, turpentine and a drier.

The more common color pigments are given in the following list. These pigments may be used singly or may be mixed to produce the color desired:

*Black Pigments:*

- Lampblack
- Gas or carbon black
- Bone black
- Charcoal black
- Graphite (black lead or plumbago)

*Red Pigments and Lakes:*

- Indian red — dark purplish
- Tuscan red — subdued crimson
- Venetian red — brick red
- English vermilion — scarlet
- American vermilion (chrome red) — brilliant scarlet
- Lakes — practically every shade of red, purple, and maroon

*Yellow Pigments:*

- Chrome yellow — deep orange to light yellow
- Zinc chromate — light yellow
- Barium chromate — light yellow
- Ocher — pale yellow to olive
- Sienna — brownish yellow

*Brown Pigments:*

- Burnt sienna — orange red
- Raw umber — yellowish brown
- Burnt umber — rich brown
- Vandyke brown — walnut
- Various mineral browns

*Blue Pigments:*

- Prussian blue — dark blue
- Ultramarine blue — pure blue to green
- Cobalt blue — greenish blue

*Green Pigments:*

- Chrome green — pale yellow green to deep blue-green
- Chrome oxide green
- Emerald green
- Verdigris — pale bluish green
- Green earth — bluish green to bluish gray

These colors are commonly furnished ground in linseed oil but most of them may also be obtained in the powdered form.

*Decorator's colors* are a finer grade of colors, ground in oil, used in high-grade interior decorating. *Fine glaze colors* are colors which do not hide the undercoats. They are ground in oil. *Water colors* are colors ground in water or "distemper" and are used for graining and the tinting of interior wall surfaces. Colors ground in Japan are pigments with varnish as a binder and have a volatile thinner.

**Red Lead.** — Red lead or oxide of lead is a brilliant red pigment used primarily on account of its very marked protective qualities. It is rarely, if ever, used as a color pigment in white lead. Red lead may be obtained as a powder or ground in linseed oil as a paste. The paint made from red lead and linseed oil forms a very tough and durable surface which is extensively used as a priming coat to protect structural steel. It tends to darken when exposed to air containing sulphur compounds and to be whitened by other agencies but such defects are not serious because its principal use is as a first or priming coat.

**Origin of Color Pigments.** — Many of the color pigments are *natural earths* consisting of earthy substances such as sand and clay mixed with such materials as the oxides of iron and manganese which provide the color. These materials are refined mechanically before being ready for use. Examples of this class of pigments are: yellow ocher, sienna, umber, and venetian red (now made artificially). Burnt umber and burnt sienna are made by calcining or burning raw umber and raw sienna. The metallic or mineral browns are made by roasting native iron ores. Green earth is a natural earth commonly composed of silicates of magnesium and ferrous iron. Vandyke brown is made from decayed vegetation, and walnut stain from walnut hulls. Carmine is obtained from an insect named cochineal. Bone black is made from animal bones which have been burned and ground to a fine powder. Carbon black and lampblack are soot or carbon made by the incomplete combustion of gas, oil, resins, or fats.

Numerous color pigments are made by chemical processes which have in many cases replaced mineral or vegetable sources. Indian red and

venetian red were formerly supplied by natural earths or iron ores which were chiefly iron oxide but are now made by roasting green vitriol which is ferrous sulphate. English vermilion is mercury sulphide and American vermilion is basic carbonate of lead, both of which are made chemically. Prussian blue is made by precipitating potassium ferrocyanide with ferrous sulphate. The pale blue precipitate thus formed is oxidized forming the dark blue pigment. The pigments known as lakes are made chemically by precipitation of a mineral such as barium sulphate, whiting, gypsum, or alumina in a solution of dyestuff causing the mineral to be colored by the dye. Dyes in solution cannot be used in paint but by coloring the solid materials just mentioned the powdered pigments are obtained and are converted into paste by mixing them with oil, varnish, or water.

## ARTICLE 84. VARNISH, ENAMEL, AND LACQUER

**Varnish.** — Varnish is defined as a liquid coating, containing no pigment, which flows out to a smooth coat when applied and dries to a smooth, glossy, relatively hard, permanent solid when exposed, in a thin film, to the air.[1] There are two general classes of varnish: spirit varnish, and oil varnish. *Spirit varnishes* are composed of resin or a similar substance dissolved in a volatile liquid such as alcohol. *Oil varnishes* are composed of resins in solution in a drying oil such as linseed oil or tung or chinese wood oil, a volatile thinner such as turpentine, and a drier.

Resins come from various sources such as the *fossil gums* formed from the gums given off by certain trees ages ago and now found buried in the ground; and *rosin* which is the residue resulting from the distillation of turpentine — a product resulting from the distillation of the resin from pine trees.

The most important resins are: the *copal*, which are fossil gums of widely varying quality and properties, that known as *Zanzibar* being the best and most costly and those known as *Kauri* and *Congo* being the most widely used; *dammar resin*, which is used extensively in spirit varnish; *rosin*, which is the residue left after turpentine has been extracted from balsum; and *lac*, which is used in making shellac.

*Shellac* is a resin obtained from stick lac, a resinous substance produced by the bites of an insect on the small twigs of several species of East Indian trees. The shellac is made by refining seed lac which is obtained from the stick lac. It is naturally orange in color and is known as *orange shellac* to distinguish it from *white shellac* which is made from the orange shellac by bleaching.

[1] Standard Definitions of Terms Relating to Paint Specifications. A. S. T. M. Standards, 1927.

Oil varnish is made by melting the resin and adding to it a drying oil such as linseed oil or tung oil which has been heated. This oil may contain the drier or the drier may be mixed separately. The use of tung oil or chinese wood oil in varnish making is rapidly increasing. After the resin and oil are mixed and cooled a volatile thinner such as turpentine or benzene is added. The varnish is then filtered and stored. If the varnish is to be stored for a long enough period filtering is not necessary. Long storage improves the quality of varnish. Oil varnish is not simply a mixture of resin, drying oil, and a drier but complicated chemical changes take place during the process of manufacture and storage. For this reason the details of the process are of utmost importance. Two varnishes made from the same materials may differ greatly in their properties.

Varnish containing a large proportion of oil is called *long oil varnish*, and varnish containing a small proportion of oil is called *short oil varnish.*

Oil varnishes are made to suit various conditions of service. *Spar varnish* is a long oil varnish made for exterior use and is highly resistant to weathering; *floor varnish* is resistant to wear and dries quickly; *rubbing varnish* is a short oil varnish which dries quickly so that it may be rubbed with powdered pumice stone and water to produce a rubbed finish; *flat varnish* dries without a gloss producing a dull matte finish.

Varnish making is a highly developed and complex industry employing many special materials and processes known only to those who have developed them but the explanation just stated will give a general idea of the methods and materials used.

Spirit varnishes are divided into several classes: *Dammar varnish,* made by treating a special resin, known as dammar resin, with turpentine or a light mineral oil; *shellac varnish,* made by treating shellac with alcohol; and *asphaltum varnishes,* which are solutions of coal tar pitch in coal tar naphtha, or *oil varnishes* with a part or all of the resin replaced by asphaltum. Asphaltum varnishes may be made resistant to acids and fumes. They may dry simply by exposure to air or may be of a composition designed for drying by baking.

**Enamels.** — Enamel may be defined as a kind of paint which flows out to a smooth coat when applied and dries to a smooth, glossy, relatively hard, permanent solid when exposed in a thin film to the air. An enamel always contains a pigment and has a considerable hiding power and color. Some enamels dry to a flat or eggshell finish instead of a gloss finish.[1] In general, enamels are paints with varnish as a vehicle and with various pigments to give the desired color. The colored pigments

[1] Standard Definitions of Terms Relating to Paint Specifications. A. S. T. M. Standards, 1927.

are usually added to a white enamel made from a white pigment such as zinc white. The surface produced by enamels is harder, smoother and more resistant to wear than a paint surface. Enamel surfaces are naturally glossy due to the varnish vehicle but if an eggshell finish is desired turpentine may be substituted for some of the varnish or by using a larger proportion of turpentine a flat enamel may be obtained. Lithopone is sometimes used to replace part of the zinc oxide as a pigment, especially in eggshell or flat enamels, because it tends to dull the luster of the enamel. The tendency of lithopone to turn gray in the sunlight is, of course, an objectionable feature. Asbestine is sometimes used on account of its property of holding pigments in suspension. Other inert extenders such as silica, whiting, and china clay are sometimes used to reduce the cost of enamel or improve its working qualities, but such adulterants should be used with caution. The undercoatings for enamel should preferably be flat enamels designed especially for that purpose, but paint is also used.

**Lacquers.**[1] — The lacquer most commonly used on the interior finish of buildings consists of a nitrocellulose base to which certain gums, solvents, and pigments have been added. Nitrocellulose is also known as *pyroxylin*, so these lacquers are also called *pyroxylin lacquers*. Nitrocellulose is a combination of nitrogen and cellulose formed by treating cotton linters (short-fiber cotton) with nitric acid. The other ingredients are selected according to the kind of lacquer desired. Lacquers are similar to enamels in composition except that nitrocellulose is used instead of linseed oil.

Some of the gums used in lacquer manufacture are Ester, Kauri, Manila, and Congo, and some of the solvents are Ethyl, Butyl or Amyl Alcohol, Amylacetate (banana oil), solvent naphtha and possibly benzene. Certain oils, such as castor oil, are used to make the film more plastic and thus reduce its tendency to crack due to expansion and contraction. These are called *plasticizers*.

Lacquers may be clear with a glossy or a flat finish like varnishes or they may be colored like varnish enamel. The pigments used are the same as those used in high-grade enamels.

The striking difference between lacquer and varnish or enamel is in the rapidity of drying. Lacquer dries by the evaporation of the very volatile solvent but varnish dries by the relatively slow oxidation of the linseed oil, the evaporation of the turpentine in the varnish merely

[1] An article entitled Proper Use of Lacquer in Vol. XLVII of the Architectural Forum and one entitled Lacquers, Composition and Uses by W. S. Colfax, Jr., in the 1927 Handbook of the Illinois Society of Architects were of considerable assistance in preparing the material on lacquers.

causing the varnish to set or thicken. Several coats of lacquer can be applied in a day. Since a large part of lacquer is volatile material the film formed by non-volatile constituents is relatively thin as compared with a varnish or enamel film.

Another difference between lacquer and varnish or enamel is in the hardness and tensile strength of the films. The lacquer film is hard and has great tensile strength whereas the varnish or enamel film is plastic and yielding. The lacquer film tends to shrink when drying, so forms a very smooth surface. It produces a hard, tough, waterproof surface that does not scratch and is easily cleaned.

Lacquer has certain peculiarities and unless it is intelligently selected and applied on a properly prepared surface poor results may be obtained. It has a relatively poor adhesion, is not elastic, and forms a thin film. Due to its lack of elasticity, lacquer is liable to crack when applied to wood because wood expands and contracts as its moisture content changes. For this reason most lacquers are not suited for use on exterior woodwork. Metals are not affected in this way by moisture, so good results are more easily secured on metal than on wood.

Due to its hardness, durability, and resistance to wear lacquer is suitable for the finishing of floors. A wax-like finish may be obtained if desired. Lacquer may be used on plaster walls which have thoroughly dried out. A priming coat on the walls is desirable before the lacquer is applied.

Surfaces which are to be lacquered must be absolutely dry and free from wax, grease, mineral oils and dust or dirt or moisture. Lacquer cannot be used over old wax surfaces or over surfaces which have been cleaned with a paint remover which contains any wax.

The surface to which lacquer is applied must be smooth because lacquer will not cover up rough and uneven spots in the way that paint, varnish, and enamel will.

It is very essential that the undercoats used with the lacquer be properly selected. Ordinary oil paints contain too much oil for use under lacquers because the solvent in the lacquer reacts with the unoxidized oil and produces a rough irregular surface. Special paints with a minimum amount of oil are prepared for use as the undercoats for lacquer.

An oil stain or a spirit stain should not be used under a lacquer unless the lacquer has been thoroughly tested over that particular stain because the lacquer may bleach the stain. Shellac under lacquer destroys its toughness. If used, it should be as thin as possible.

Lacquers are divided into spraying, brushing, and dipping lacquers depending upon their suitability for each of these methods of applying. The difference in these lacquers is in the solvents used. Those in spray-

ing and dipping lacquers evaporate too rapidly for brushing. The ordinary brushing lacquer dries too quickly for use in covering large surfaces, so slow-drying lacquers are made using slow-evaporating oils. These oils are expensive so the slow-drying lacquers cost more than the ordinary brushing lacquers.

Brushing lacquer can be applied by ordinary brush or spray brush but spraying lacquer can be applied only with the spray brush. Excellent results are secured by spraying. Brushing lacquers contain solvents which act on the preceding coats, therefore a painter must adopt different methods than those he uses with oil paint. He must work rapidly and not go back over surfaces which have just been lacquered and by going over a surface several times he may soften the undercoats. Since lacquer is self-leveling on account of its tendency to shrink in drying it is not necessary to go over a surface as much as in oil painting.

**Bronze Paints.** — Bronze paints which are often used for painting radiators and other interior metallic surfaces are made from metallic pigments such as aluminum bronze, which is finely divided aluminum, copper bronze, which is finely divided copper, and other metals or alloys, with a vehicle of banana oil or a china wood oil resin varnish with a petroleum oil thinner.



A common vehicle for bronze paints is nitrocellulose lacquer called *bronzing liquid* made by dissolving nitrated cotton (nitrocellulose) in amylacetate. This bronzing liquid is sometimes called banana oil but this name applies only to amylacetate and not the solution of nitrated cotton in amylacetate.

The bronzes are made by beating the metals into the thin leaf form with steam hammers, then converting them into the flaky powders by forcing the leaf through a fine mesh sieve using a scratch brush, grinding in oil, removing some of the oil by water, and finally removing the remaining oil by pressing.

## ARTICLE 85. STAINS AND WATER PAINTS

**Wood Stains.** — Wood stains are used to color the grain of woodwork and bring out its texture. They are classed as oil stains, water stains, spirit stains and acid stains. *Oil stains* consist of pigments and oil to which a thinner, such as turpentine or benzene, has been added in sufficient quantity to enable the stains to penetrate into the wood; *water stains* are solutions of dyes in water; *spirit stains* are solutions of dyes in alcohol; and *acid stains* consist of acids, salts, and alkalies which are used to produce various effects by their action on wood.

Water stains and spirit stains raise the grain of the wood while oil

stains do not, but the water stains and spirit stains have a greater penetrating power than oil stains and produce a clearer finish. Spirit stains are also called *penetrating stains.* Pigments commonly used in oil stains are siennas, umbers, and ochers, and in some cases aniline dyes are used. Aniline dyes are used for coloring water stains and spirit stains.

The acid stains include many materials which are not acids. These materials include nitric acid, hydrochloric acid, ammonia, potassium bichromate, copper sulphate and many other chemicals which act on woods, such as oak, which contain tannic acid to change the natural color and produce a stained appearance.

Varnish stains are thin varnishes to which a coloring material has been added. They differ from enamels chiefly in that they are transparent and do not hide the grain of the wood.

**Shingle Stains.** — Shingle stains are intended to preserve and color shingles but do not bring out the grain. They are usually oil or spirit stains with creosote oil added as a preservative.

**Water Paints.** — The paints having water as a vehicle are: whitewash, calcimine, and cement wash. They are sometimes called *distemper paints.*

Whitewash is made from quicklime slaked with water or from hydrated lime, which is lime which has been slaked at the mill. Water is added to the slaked lime to make it thin enough to apply with a brush. Flour, skimmed milk, glue, molasses or other substances may be added to increase its adhesion. Preservatives such as salt or formaldehyde should be added to keep these substances from spoiling. Whitewash is the cheapest paint available and has desirable sanitary properties. It may be tinted by the use of pigments.

Calcimine is made from whiting, which is powdered lime carbonate; water; some material such as glue or casein as a binder which will hold this mixture to the surface to which it is applied; and a pigment to give the desired color. Calcimine may be prepared by the painter or may be purchased from manufacturers in a powdered form ready for the addition of water. In general, the prepared calcimines are mixed with cold water to form cold-water calcimines or cold-water paints, but some require boiling water and are called hot-water calcimines. The pigments used to color calcimine are the same as those used for oil paints but they are furnished in the powdered form and are called *distemper colors.*

*Cement wash* is simply a thin grout made of portland cement and water and of such a consistency that it can be applied with a brush. Fine sand is sometimes added. This wash may be colored if desired and with some tints it is desirable to use white portland cement.

## ARTICLE 86. MISCELLANEOUS PAINT MATERIALS

**Floor Wax.** — Floor wax is made from beeswax and paraffin wax with other materials such as turpentine and gasoline added to make a workable mixture.

**Putty.** — The putty used in connection with painting may be whiting putty or white-lead whiting putty. *Whiting putty* is a mixture of finely powdered natural chalk, called whiting, and linseed oil. *White-lead whiting putty* has the same composition as whiting putty except that about 10 per cent of the whiting is replaced by white lead. Putty is given the desired color by adding a minimum amount of colored pigments. Putty hardens by the oxidation of the linseed oil.

Putty is used for filling knot holes, dents, nail holes, cracks and other defects in wood surfaces preliminary to painting. It is applied after the primary coat of paint in order that too much of the linseed oil in the putty will not be absorbed by the wood. Putty is also used to hold glass in window sash and doors as explained in Article 72. Putty used on steel sash must be of special composition.

**Fillers.** — Fillers are commonly used on open-grained woods, such as oak, chestnut, and ash, to fill the pores before applying varnish. Fillers are of two classes: paste fillers and liquid fillers. They should not conceal the grain of wood or dull stained woods and so should be as nearly colorless and as transparent as possible.

*Paste fillers* should preferably consist of silex, which is powdered silica or quartz, and a quick-drying varnish mixed in proportions which will yield a paste. Barytes, clay, whiting, and gypsum are used to a certain extent on account of their cheapness but they give an inferior product. Paste fillers may be colored, if desired, by the addition of pigments or stains. Paste fillers are thinned with turpentine before using and are rubbed into the wood with short stiff brushes. After the filler has set for a few minutes the part which has not been taken up by the wood is removed.

*Liquid fillers* may be paste fillers which have been thinned, they may be thin varnishes, or they may be a mixture of gloss oil, linseed oil, and a pigment such as asbestine, or china clay. The latter type is unsatisfactory. Shellac in alcohol is frequently used as a liquid filler. Most liquid fillers are designed for use on close-grained woods. Paste fillers are more commonly used than liquid fillers.

**Pumice Stone.** — This stone of volcanic origin, imported from Italy, is used in the form of a gray powder for rubbing paint, varnish and enamel to remove the gloss and form a smooth surface. It is used with water or a non-drying oil. Pumice stone is available in several grades of fineness.

**Rotten Stone.** — This white powder is finer than pumice stone but is used in the same way. It produces a finer finish than pumice stone. Several grades of fineness are available.

**Sandpaper.** — Sandpaper is made by glueing ground flint to manila paper. It is used for smoothing the surface of lumber and of paint, varnish, or enamel, or removing paint, varnish or enamel. Sandpaper is available in several grades of fineness.

**Steel Wool.** — Steel wool consists of fine shreds of steel matted together for use in the same manner as sandpaper. It is available in several grades of fineness.

**Curled Hair.** — Curled hair is usually horsehair. It is used to rub the surface of varnish or enamel to reduce the gloss.

**Excelsior.** — Excelsior is shredded wood. It is used in the same manner as curled hair.

## ARTICLE 87. MIXING AND APPLYING

**Mixing.** — White oil paint forms the basis for oil paints of all colors. In mixing white-lead paint, the white lead, which comes mixed with linseed oil to form a paste, is first "broken up" by adding linseed oil, a little at a time, and working it in with a paddle. When the paste has all been converted into a heavy liquid of uniform consistency it is thinned the desired amount by adding more linseed oil. If linseed oil is added in large amounts to the paste before it is broken up the thinned paint will contain lumps of white lead which are difficult to break up. In mixing lead-zinc paints the white-lead and zinc-white pastes are broken up separately and mixed after they have each been thinned to about the desired consistency. Driers are preferably added to the white paint after the paste has been broken up but before it has been thinned. Colored paints are made by adding the proper color pigments to white paint. These pigments are first broken up and thinned with linseed oil and turpentine. The lumps and skins are removed from paint by straining through fly screen or cheesecloth fastened over the top of a pail. Black paint and red-lead paint are made from the pigments without the use of a white paint base.

Ready-mixed or prepared paints are on the market. To insure good quality, prepared paints made by reliable manufacturers should be purchased. If after opening a can of prepared paint, it is found that the pigment has settled to the bottom forming a thick paste, the liquid portion should be poured into another can. The paste should then be stirred with a paddle, and the liquid slowly added to the paste, the stirring being continued. Prepared paints are available in a great

variety of compositions and colors and to suit various conditions of service.

Enamels are not usually prepared by the painter since better results are obtained with enamel prepared by the manufacturer. Pigments which have settled to the bottom of the can are broken up in the same manner as described for prepared paints.

Varnish is manufactured ready for use and its composition should not be altered by the painter. It is not simply a mixture, like paint, but is the product of chemical reactions which cannot be duplicated on the job. Small amounts of turpentine are sometimes added to make varnish thinner but this practice should be avoided if possible except where thin varnish is used as a filler.

**Preparation of Surface.** — For the best results, the material to be painted should absorb the vehicle to such an extent that a sufficient penetration to anchor the paint film will be secured. For reasons of economy, however, excessive absorption is undesirable. Surfaces which are wet, or covered with a coating of oil, grease, dust, or any foreign matter which will interfere with the penetration or adhesion of the paints or varnishes are obviously not in condition to receive the paint or varnish. Some materials contain substances which react with some of the constituents of the paint or varnish and eventually destroy them. Under these circumstances a treatment is necessary to remove, to seal, or to neutralize these substances so that they will not be harmful. Considering only the adhesion of the paint, it is desirable that wood and metal surfaces be exposed to the weather for at least a short period before painting. This raises the grain of the wood slightly and removes the oil film which may be on the metal and results in better adhesion. Weathering, however, may cause wood to shrink, crack, and warp and steel to rust, so exposure to the weather may be undesirable from this point of view.

White pine, poplar, redwood, maple, birch, and Douglas fir are excellent bases for paint, varnish, and enamel and require no special treatment. They are close-grained and thus require no filler and absorb the paint readily enough to insure the anchorage of the paint film but not in excessive amounts. White pine and poplar are not often varnished because their grain is not attractive. Birch takes stain exceptionally well.

Hard or yellow pine and cypress are filled with pitch or gum to such an extent that it is very difficult to make surface coatings adhere to them. In extreme cases it may be necessary to treat the surfaces of these woods with benzol, solvent naphtha, or turpentine just before application of the paint or other coatings. These materials tend to dissolve the gum or resin enough to increase the adhesion of the paint.

Oak, chestnut, and walnut are open-grained woods which require a

filler. The filler fills the grain, reduces the absorption or "suction," and gives an even surface to receive paint, varnish, or enamel. Oak and walnut are usually varnished and are rarely painted or enameled.

Sappy wood and knots should be treated with a solution of shellac in alcohol to keep the resin from destroying the paint film by dissolving the oil. This operation is known as *knotting*. It is particularly important on surfaces exposed to the sun.

Concrete and plaster surfaces which have not aged for long periods may contain free lime which will react with linseed oil to form a soap. This soap is readily dissolved by rain leaving only the pigment without a binder to hold it in place. The harmful effect of the free lime may be overcome by treating the surfaces with a wash consisting of zinc sulphate and water. After this coating has dried for two or three days the surfaces may be painted or enameled. Before painting, it is desirable to go over the surface with a brush to remove any crystals which have formed. Other chemicals are used, but zinc sulphate is the most common. Concrete surfaces absorb paint to such an extent that it is desirable to use a filler to decrease the absorption or "kill the suction." The zinc sulphate accomplishes this to a certain degree but it is usually desirable to use the filler in addition to the zinc sulphate. Special fillers are on the market for concrete surfaces.

The treatment should not be so effective as to do away with all of the absorption for in that case the paint would not adhere firmly. If plaster walls are to be calcimined, the absorption is usually decreased by using a coat of *size* to decrease the suction. The glue size usually used consists of a solution of glue and water. Sizes are sometimes used on walls which are to be painted, but this practice is not desirable.

Metal surfaces are difficult to paint satisfactorily. New surfaces may be coated with a thin film of oil or may be covered with mill scale and, in the case of iron and steel, old surfaces may be rusted. The oil may be removed by scrubbing with soap and water or wiping with a cloth moistened with benzene. Rust, mill scale, etc., are removed by scraping, wire brushing, or sand-blasting. The oil film which covers new galvanized steel sheets is treated with a thin coating of copper chloride, copper acetate, or copper sulphate. Another solution which is used consists of equal parts of copper chloride, copper nitrate, sal-ammoniac, and hydrochloric acid. A weak solution of acetic acid is extensively used and may give satisfactory results. These coatings are allowed to stand for several hours and are then washed with clean water and permitted to dry before the priming coat is applied.

**Priming Coat and Other Undercoats.** — The first or priming coat for wood surfaces should be thin enough to penetrate into the wood so as to

insure satisfactory adhesion and it should dry flat to provide a good base for the next coat. For these reasons, the proportion of turpentine is relatively high, particularly on such woods as hard pine and cypress which do not absorb paint readily. The materials used in the priming coat should be the same as those in subsequent coats but the proportions may vary. The best priming coat on metal is probably a red lead and oil paint. The priming coat for enamel finish may be either enamel or oil paint.

After the priming coat is applied all nail holes, cracks, and similar surface defects should be filled with putty.

For the best results, it is desirable to sandpaper lightly each coat of paint, enamel, and varnish before the next coat is applied. This removes the rough spots caused by dust particles and provides a better surface for the adhesion of the next coat. The finest sandpaper should be used, taking care not to cut through the film. After sanding, surfaces should be wiped clean. Curled hair and excelsior are sometimes used instead of sandpaper to remove the gloss on varnish. The coat which preceeds the finish coat may be rubbed with pumice and water instead of sandpaper to secure the highest grade of finish for enamel or varnish.

Ample time must be allowed for each coat to dry before the next is applied. For the best results it is desirable to strain the paint, varnish or enamel several times during a painting operation. The brushes must be kept clean.

At least two undercoats should be used for paint and varnish and three or four undercoats for enamel.

**Finishing Coat.** — Paint may have a gloss, an eggshell finish, or a flat finish depending upon the amount of turpentine and upon the pigments used. A small amount of varnish is sometimes added to the finishing coat to increase the gloss. Outside surfaces should have a gloss finish because this is not so easily soiled, but an eggshell or flat finish is usually more attractive for interior work.

Enamels and varnishes will naturally have a gloss finish but those which dry without gloss are extensively used. A dull finish may be produced by rubbing the final coat of gloss finish with a very fine steel wool or with pumice stone in water or a non-drying oil. This is usually done with a felt pad but a brush with the bristles cut short may be used for quicker but less satisfactory results. After a surface has been rubbed to a smooth dull luster it is polished with rotten stone and a non-drying oil. After the polishing is completed the surface is cleaned with a soft cloth dampened in benzene and rubbed with a chamois-skin.

The surface of oil paint is sometimes finished by *stippling*. This is

done by striking the wet paint many blows in rapid succession with a brush with stiff bristles. Tiny closely-spaced indentations are made in the surface of the wet paint giving it a flat appearance when dry.

Painted surfaces may be made to resemble oak or other woods with a prominent grain by a process known as *graining*. This is done by first painting the surface a light color. After this coat has dried, paint of a darker color is applied to the surface. While this paint is still wet a leather or steel graining comb, a rubber grainer, a brush, or a cloth is drawn over the surface in such a way that it removes a part of the dark paint leaving streaks or patterns to resemble the grain of wood. The choice of colors and the pattern of the grain depend upon the wood which is being imitated. By this process, wood without grain, such as white pine or poplar, is made to resemble such woods as oak. Metal surfaces are also made to resemble wood surfaces.

A *wax finish* may be applied to wood with or without undercoats of varnish or shellac. If no varnish or shellac is to be used the wax is applied to the wood after it has been filled. After the wax has dried it is polished with a weighted brush for floors or with a flannel for wood trim. More than one coat is usually applied. Better results can be secured if one or two coats of varnish or shellac are applied to the wood after it has been filled and before waxing.

**Weather Conditions.** — To secure good results, paint or varnish should not be applied in damp, humid weather nor at times when the temperature is below 50 deg. fahr. For varnish and enamel the temperature should be above 60 deg. and preferably above 70 deg. fahr. Every precaution should be taken to keep dust or dirt from blowing on paint, varnish or enamel before they are dry.

**Methods of Applying.** — The usual method of applying paint and varnish is with a brush, but small articles may be coated by dipping them in vats of paint, or varnish, and nearly all classes of work may be done by air spraying.

The best brushes are made from the bristles of swine raised in China and Russia but horsehair is sometimes used as an adulterant or to make brushes stiffer. The bristles of brushes are set in cement or rubber.

Spraying is carried on by paint-spraying machines which by means of compressed air force the paint against the surface to be painted. The power for operating these machines is furnished by gasoline engines or electric motors. The compressed air is forced into a tank called an air receiver and the paint is placed in the paint tank. Compressed air forces the paint through a hose to the spray gun which the operator holds. In order to form a spray of the paint and not a stream, compressed air is supplied to the air gun through another hose. This air comes in contact

with the paint forming a spray which is forced against the surface to be painted. The whole apparatus is controlled by suitable valves to produce the desired results. The spray is turned on and off by a trigger on the gun. The gun is moved over the surface to be painted and is kept 6 or 8 in. away from it. The air spray is effective where large areas are to be covered but is also used on small articles. Spraying requires somewhat more paint than hand brushing but the labor cost is less for work to which spraying is adapted.

## ARTICLE 88. OTHER PROTECTIVE COVERINGS FOR METAL

**Methods.** — Steel or iron may be protected from corrosion by coating them with protective coverings of zinc as in the *galvanizing* and *sherardizing processes*, with a coating of tin as in *tin plating*, an alloy of lead and tin as in *terne plating*, a coating of nickel as in *nickel plating*, or a coating of copper as in *copper plating*. Nickel plating is also applied to copper and brass to give the desired surface finish. The surface of steel or iron is protected by cadmium in the *Udylite process*, which is not extensively used. Vitreous enamels are used on bath tubs, sinks, etc.

**Galvanizing Process.**[1] — A coating of zinc may be placed on the surface of steel or iron by three different processes; the hot-dip process, the sherardizing process, and the electrolytic process. In all of these processes it is first necessary to clean the surface of the iron or steel by pickling in acid to remove all scale or oxide.

In the *hot-dip process* the metal to be treated is passed through a bath of molten zinc which forms a coating of zinc on the surface, the thickness of the coating depending upon the temperature of the bath, the time in the bath, and the extent the sheets are wiped after coating. This process with modifications is used for sheet metal, pipe, wire, and articles of various shapes. It is practically the only process used for sheet metal and pipe.

The *sherardizing process* is used primarily for coating small irregular-shaped articles and consists of heating the articles in a revolving iron drum with powdered zinc. The zinc is volatilized and deposited on the iron forming a coating which conforms sharply to the original lines of the object being coated.

The *electrolytic process* is usually applied to small irregular-shaped articles. The coating is applied by depositing zinc electrolytically from a solution of zinc salts.

**Plating Processes.** — In *tin plating*, iron or steel sheets which have been thoroughly cleaned by pickling in acid are passed through baths of

[1] Bureau of Standards Circular 70.

molten tin and rolled to remove the surplus tin. *Terne plating* is carried out in the same way except that the baths contain a molten mixture of tin and lead.

*Nickel plating* and *copper plating* are usually done by the electrolytic process. The article to be plated is made the cathode. The anode is composed of the same material as the plating. The anode and cathode are immersed in a bath containing a solution of a nickel or copper salt depending upon the kind of plating. The metal is deposited on the cathode and the anode decreases a corresponding amount, the composition of the bath remaining constant. It is necessary to copper plate steel before it can be nickel plated.

**Vitreous Enamels.** — In applying *vitreous enamels* to cast iron or steel the metal is first thoroughly cleaned by pickling in acid or in some other way. The first coat, consisting principally of silica from sand or quartz, alumina from clay, and lime is applied wet. After this coat has dried it is heated in a furnace to fuse the enamel. The composition is such that the first coat is usually blue. The metal is removed from the furnace and a powder which will form a white enamel is sifted on the surface. The metal is then heated again until the second coat of enamel is fused. This process is repeated until the desired number of coats is obtained. Enameled iron and steel are used for bath tubs, sinks, and other sanitary ware.

CHAPTER XVI

# PLANS, SPECIFICATIONS, CONTRACTS, BONDS, AND INSURANCE

## ARTICLE 89. PLANS AND SPECIFICATIONS

The contract between the party for whom a building is to be constructed and the contractor who is to construct all or any part of the building consists of the agreement between the owner and the contractor, the specifications for the work, and the plans.

The plans and specifications for a building must furnish all of the information necessary for estimating the cost of a building and carrying out the construction according to the ideas of the architect or engineer. Explanations and instructions which may be required after the contract is awarded should be reduced to a minimum, for they are a frequent source of trouble and litigation.

It is essential that one who is to be engaged in building construction or estimating must be able to read plans. Skill in reading plans can be gained only by experience, but a few comments concerning the preparation of plans may be of some assistance.

The drawings included in a set of plans are of course made smaller than the parts of a building which they represent. For small buildings such as dwelling houses, $\frac{1}{4}$ in. on the plans is equivalent to 1 ft. in the building and the scale is said to be $\frac{1}{4}$ in. to the foot. For buildings, the scale is commonly $\frac{1}{8}$ in. to the foot. Other scales are used for special purposes as will be explained later. The scale of $\frac{1}{4}$ in. to the foot is commonly called a quarter-inch scale, similar designations being used for other scales.

Several different kinds of drawings are included in a set of plans. The more common drawings are described in the following paragraphs.

**Floor Plans** are horizontal sections taken about 4 ft. above the floor level and show all of the walls, partitions, columns, windows, doors, flues, chases, stairways, elevator shafts, radiators or registers, plumbing fixtures, electric-light outlets, blackboards, and all other items which would be visible if a horizontal section were taken. Wall openings which are not intersected by this horizontal section are included in the plan if this can be done without confusion. Features which are on the ceiling above, such as exposed beams and breaks in the ceiling surface, are shown dotted on the floor plans. Except in very simple buildings, detailed structural features, water and steam pipes, electric conduits, etc.

are not shown on the general floor plans but are shown on special sets of plans.

**Elevations** are really exterior side views, end views, etc., as they would be seen if projected on vertical planes. They show the outlines of the building and all exterior features such as windows, doors, cornices, belt courses, quoins, entrances, porches, etc. Dimensions can be scaled from elevations.

**Sections** are vertical sections through the building. They show all of the cut portions and everything which would be exposed if the near portion of the cut building were removed. Sections taken the long way of a building are called *longitudinal sections,* and those across a building *transverse sections.* Sections are not necessarily continuous but may be along a broken line in which case the broken line will be shown on the plans and will be marked so that it can be identified.

**Details** are used to illustrate parts of a building which can not be clearly shown on the plans, elevations, and sections. They are usually drawn to a larger scale than the rest of the plans and where it is necessary to show the actual curves on moldings and similar pieces they may be made full size.

**Ground Plans or Block Plans** show the location of the building on the ground, the original topography or shape of the ground surface and the topography after the building is completed and the grading is done; existing sidewalks, streets, drives, etc.; sidewalks, streets, drives, etc., which are to be provided; existing water and gas mains; sewers, electric lines, telephone lines, etc.; and trees which are to be removed or which are to be left in place. Any planting which is to be done will usually be shown on a separate drawing. A boundary outside of which no work is to be done is usually shown. This is called the *contract line.* A scale of $\frac{1}{16}$ in., $\frac{1}{32}$ in., or $\frac{1}{64}$ in. to the foot is used on the block plans.

**Perspective Drawings** are sometimes prepared to show how a building will look when viewed from various positions, one drawing being required for each position. They show the true appearance but elevations do not. Perspective drawings are useful in showing the appearance of a building but are of no use in construction. Dimension cannot be scaled from perspective drawings.

**Models** made of plaster of paris, paste-board and other materials are often useful in showing how a building will look from all angles. They are prepared chiefly for the benefit of the client. An effort is made to make the model resemble the proposed building and grounds as closely as possible.

**Structural Plans** are necessary for all but the simplest buildings. They usually consist of a *foundation plan* showing the position, size and

make-up of the foundations and footings; *framing plans* for each floor showing the sizes of all beams and girders; a *column schedule* showing the material in each column; and *typical details* of truss joints, beam connections, column splices, and column bases. These plans are commonly drawn to the scale of $\frac{1}{8}$ in. to the foot with the exception of the typical details which are usually drawn to a scale of $\frac{1}{2}$ in. or $\frac{3}{4}$ in. to the foot.

**Shop Plans** are usually prepared by the company which receives the contract for the structural steel. They are prepared using the information given on the structural plans and must meet with the approval of the architect or engineer. Shop plans are prepared for the use of the shop which fabricates the structural steel. They must show the dimensions of every piece, the location of every rivet and all other data necessary to construct each piece. Shop plans for structural steel are highly conventionalized and are not usually to scale.

**Erection Plans** are prepared by the structural steel fabricator for use in the erection of the structural steel. These plans show the shop number of each steel member and the position it is to occupy in the building.

Reinforced-concrete construction requires plans showing the size and position of all reinforced-concrete members, the size, shape, and position of all reinforcing steel, and typical details. From these plans, *bar schedules* or lists are prepared. These lists give the size and length of every bar which goes into the structure. The necessary dimensions for all bent bars are given.

Timber construction is shown by framing plans and typical details, but since timber is commonly cut to length on the job such plans are not as extensive as steel and reinforced-concrete plans.

The structural plans are usually prepared by a structural or architectural engineer. For simple buildings the structural features may often be indicated with sufficient clearness on the general plans.

**Cut Stone or Terra Cotta Plans** are prepared from the architect's plans by the contractor who furnishes this material. *Setting plans* show the number and position of each piece of stone or terra cotta. *Shop drawings* give the data necessary for the shop or mill in shaping the various pieces. *Templets* are prepared to test the shape of cut-stone moldings. These templets are checked by the architect. Full-size details are often required for parts of the work. When the necessary information cannot be satisfactorily given by means of drawings, the architect prepares models of plaster of paris for the use of the stone or terra cotta manufacturer.

**Plumbing Plans** are commonly required to show the size and location of all plumbing pipes and fixtures which are included in the building. These fixtures are usually shown on the general plans also.

**Heating Plans** show the size and location of all steam lines, radiators, boiler, temperature control, registers and furnaces, and other features included in heating systems. The radiators, registers, boiler, or furnace are usually shown on the general plans also.

**Ventilating Plans** show the size and location of all ventilating ducts, air intakes and exhausts, air washes, and fans. They may often be combined with the heating plans. The heating and ventilating plans of large buildings are usually prepared by an engineer who specializes in this kind of work.

**Electric Wiring Plans** show the capacity and location of all electric outlets, switches, switchboards, transformers, and motors. The sizes of all conduits and wires are given and all other information necessary for the complete electrical installations is included. The data for the telephone installation may be shown on these plans or may be given on a special set of plans.

**Symbols.** — It is of course impossible to draw an accurate picture of every part of a building on the plans, therefore symbols have been devised to represent such features as windows, doors, electric outlets, plumbing fixtures, radiators, steam lines and other parts of a building. In general, these symbols resemble the object which they represent but this is not always true. Symbols have become fairly well standardized so that one who is familiar with plans can readily interpret them.

The symbols for windows, doors, plumbing, heating, electric wiring, and various materials are given in Figs. 159 to 163. The symbols or conventions used on structural steel drawings are given in Fig. 99 and those for steel windows in Fig. 148. A part of a simple floor plan showing the use of symbols is shown in Fig. 163.

**Specifications** define the work to be performed, the conditions under which it is to be carried on, the quality of material, and class of workmanship required. Construction methods are left to the contractor.

The conditions under which the work is to be carried on are grouped under the head of *General Conditions*. Some idea of the content of the General Conditions can be obtained from the following list of the article headings of the Standard Form of the American Institute of Architects:[1]

1. Definitions
2. Execution, correlation and intent of documents
3. Detail drawings and instructions
4. Copies furnished
5. Shop drawings
6. Drawings and specifications on the work
7. Ownership of drawings and models
8. Samples
9. Materials, appliances, employes
10. Royalties and patents

[1] May be obtained from the Secretary, Octagon Building, Washington, D. C.

11. Surveys, permits, and regulations
12. Protection of work and property
13. Inspection of work
14. Superintendence: supervision
15. Changes in the work
16. Claims for extra cost
17. Deductions for uncorrected work
18. Delays and extension of time
19. Correction of work before final payment
20. Correction of work after final payment
21. Owner's right to do work
22. Owner's right to terminate contract
23. Contractor's right to stop work or terminate contract
24. Applications for payment
25. Certificate of payments
26. Payments withheld
27. Contractor's liability insurance
28. Owner's liability insurance
29. Fire insurance
30. Guaranty bonds
31. Damages
32. Liens
33. Assignment
34. Mutual responsibility of contractors
35. Separate contracts
36. Subcontracts
37. Relation of contractor and subcontractor
38. Architect's status
39. Architect's decision
40. Arbitration
41. Cash allowances
42. Use of premises
43. Cutting, patching, and digging
44. Cleaning up

For detailed discussion of these General Conditions see brochure published by the American Institute of Architects and reprinted in the American Contractor, December 22, 1928 to January 12, 1929.

The remainder of the specifications are commonly grouped according to the classes of work such as:

1. Clearing site
2. Excavation
3. Footings and foundations
4. Masonry
5. Reinforced concrete
6. Carpenter and mill work
7. Structural steel
8. Ornamental iron
9. Sheet metal
10. Lathing and plastering
11. Painting
12. Roofing
13. Plumbing
14. Heating and ventilating
15. Electric wiring

etc.

These parts of the specifications cover the quality of material, class of workmanship, and dimensions and other information not shown on the plans and all other items necessary for the complete understanding of the work which will be required of the contractors.

## ARTICLE 90. FORMS OF CONTRACT

**Introduction.** — Construction work may be carried on by force account or day labor, or by contract. In *force account* or *day-labor* construction, the owner employs the men who are to carry on his work and

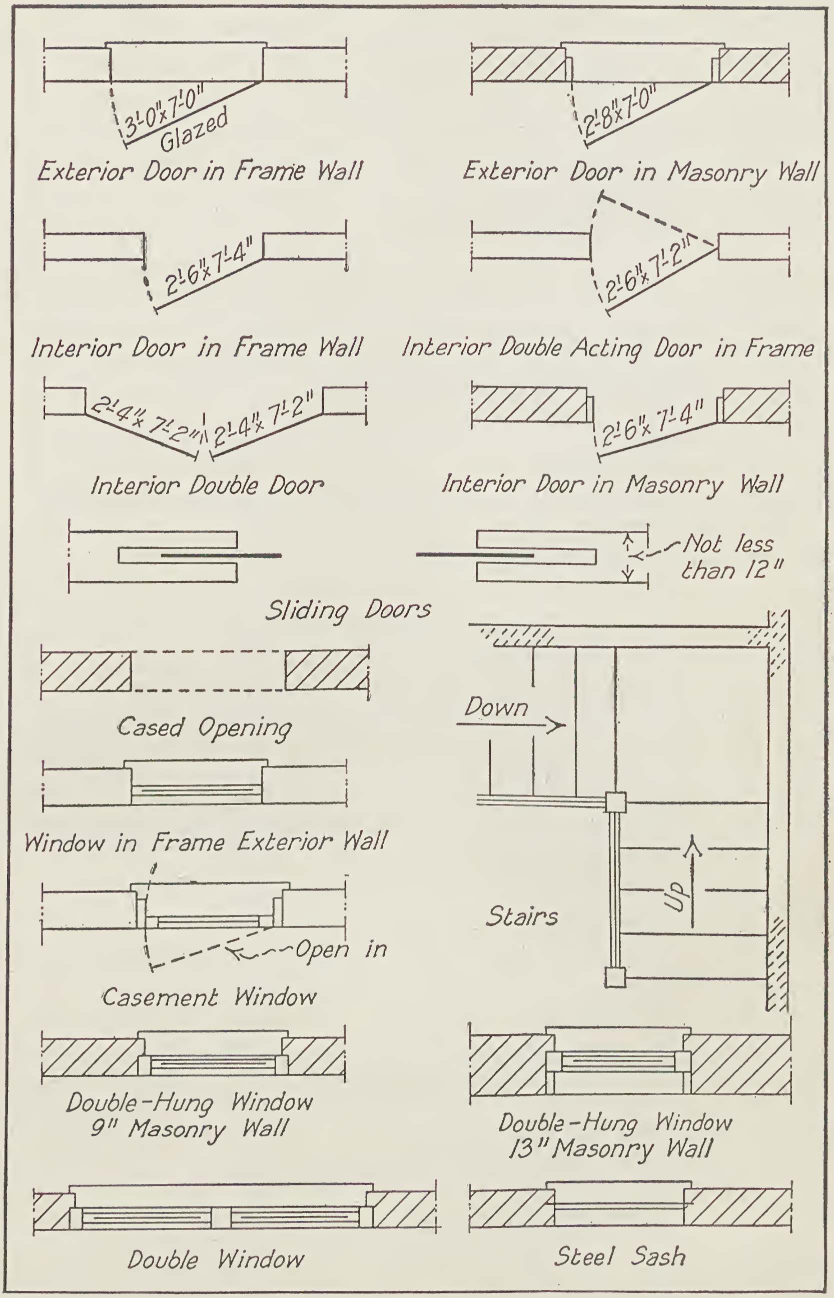


FIG. 159. Symbols for Windows, Doors and Stairs

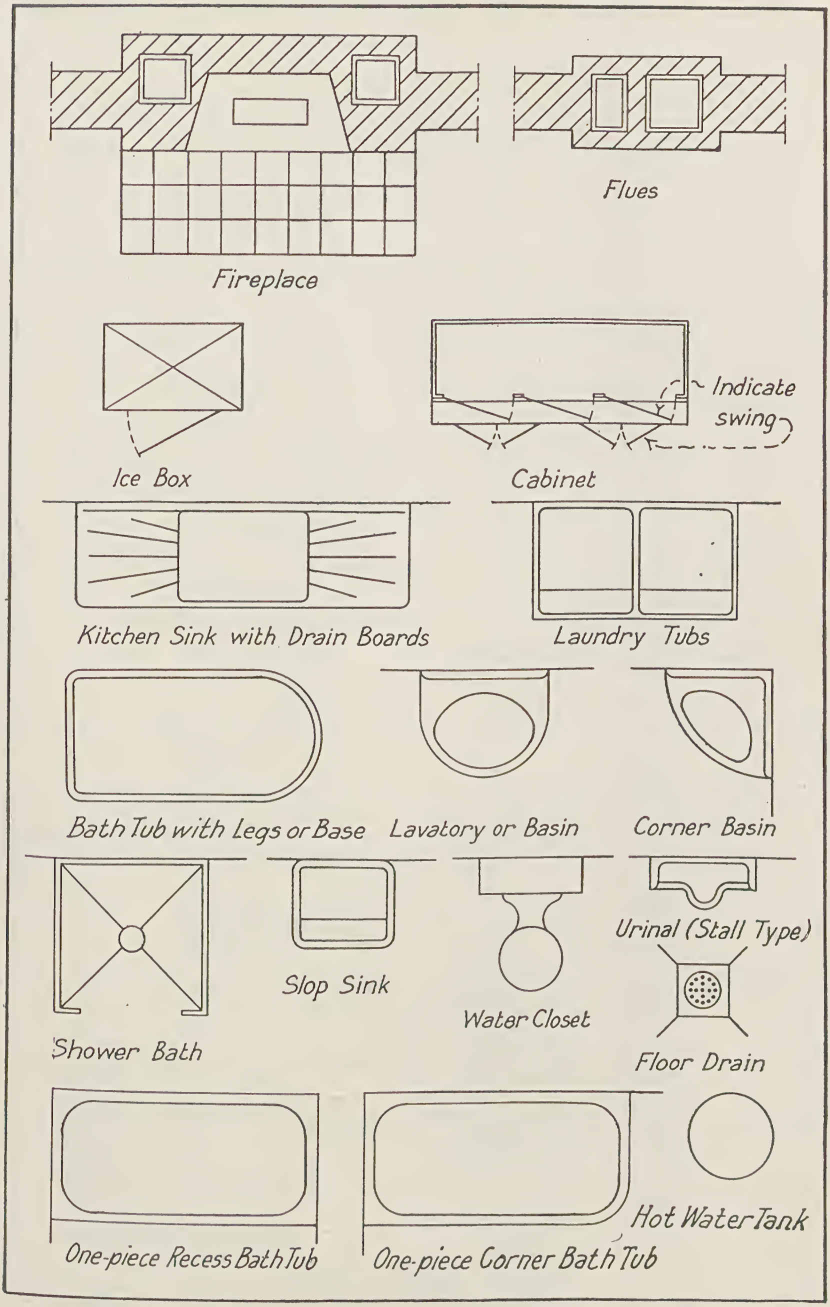


Fig. 160. Symbols for Plumbing Fixtures, Fireplaces, and Flues

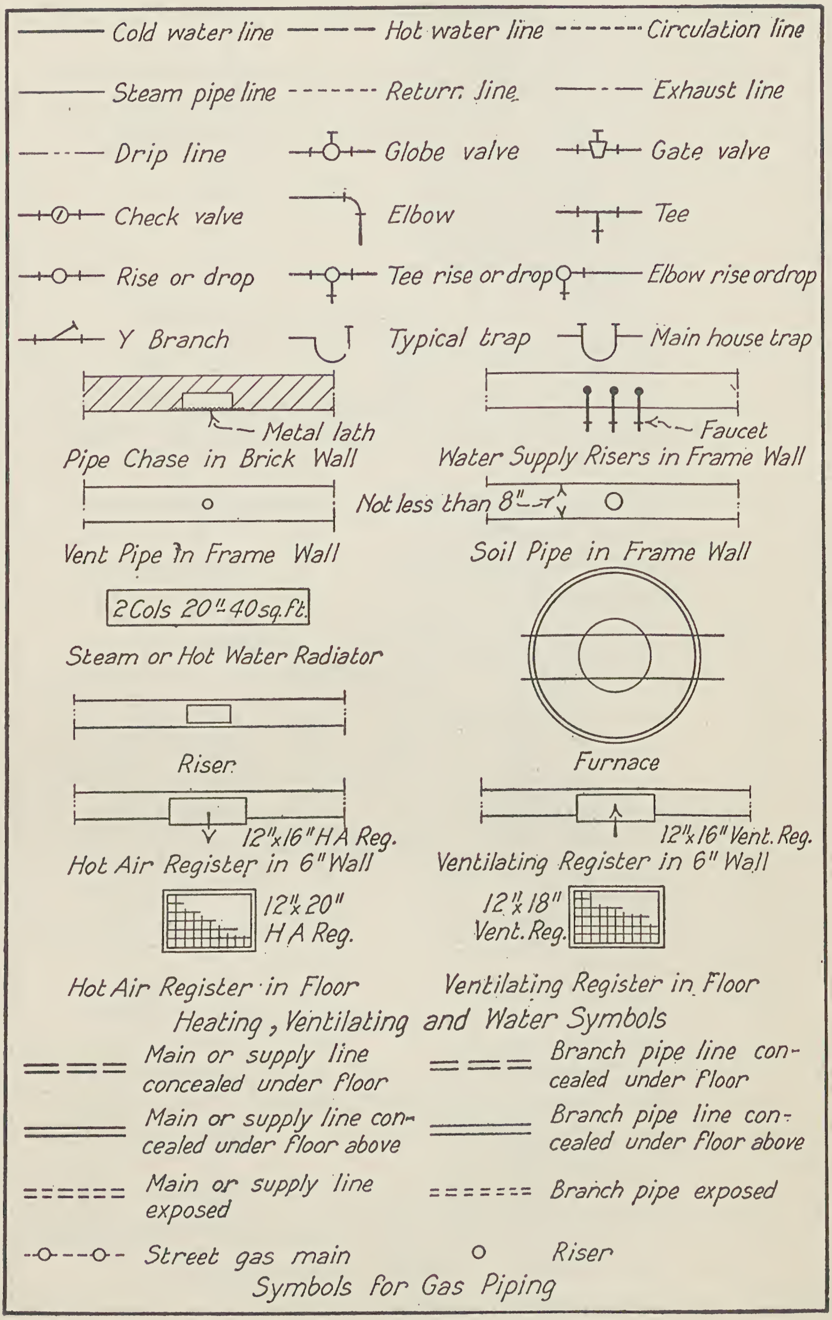


FIG. 161. Symbols for Plumbing and Heating

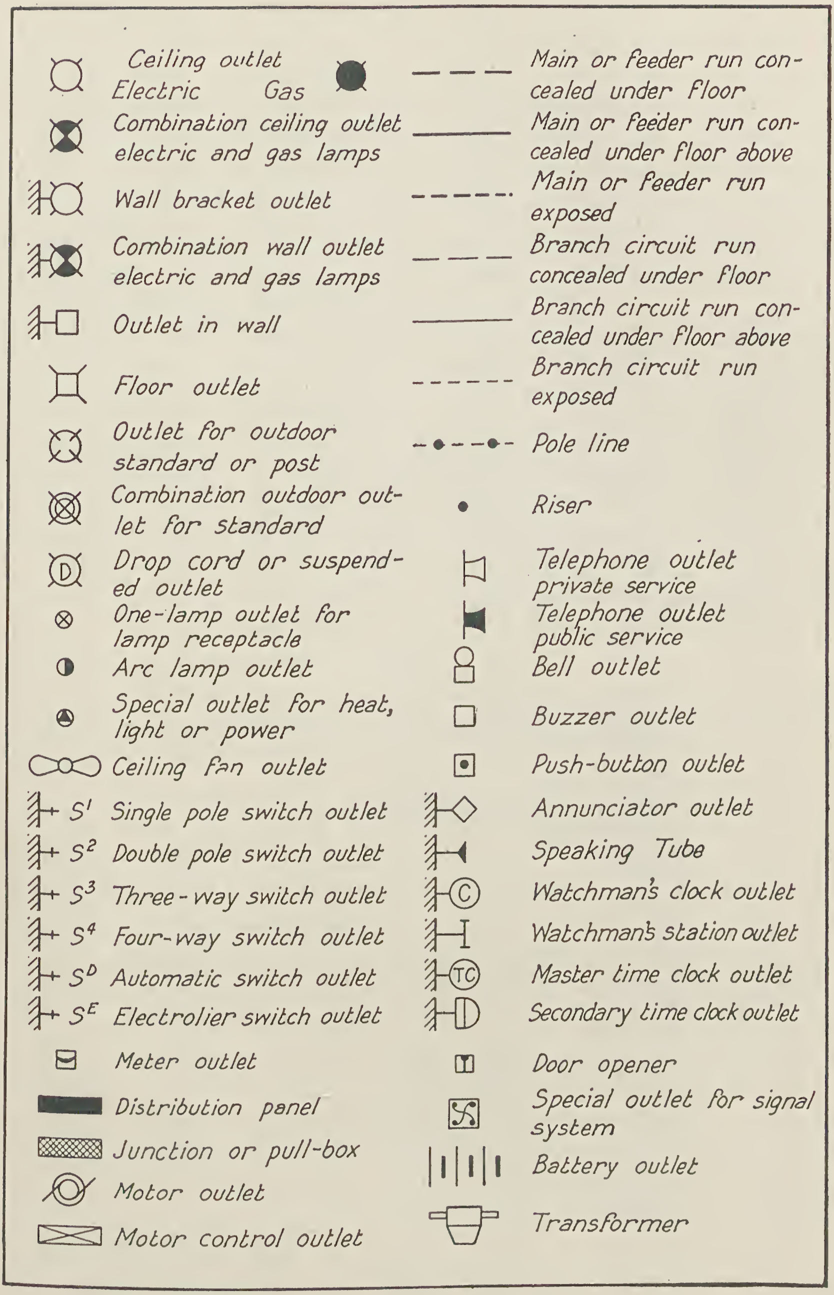


Fig. 162. Symbols for Electric Wiring

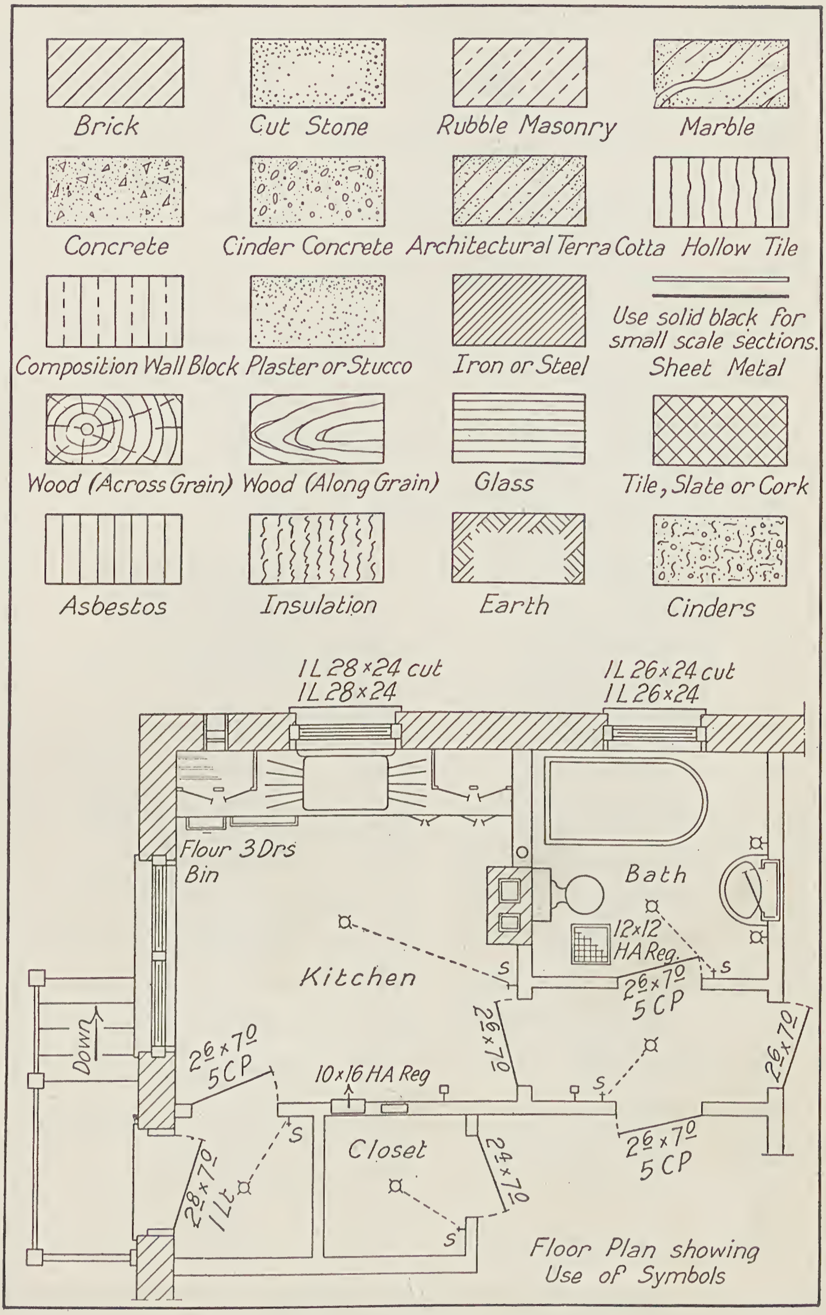


Fig. 163. Symbols for Materials and the Use of Symbols

places a foreman or superintendent in charge of them or he may employ a foreman or superintendent whose duty it is to employ the men to work under him and to direct the work of the men. He also buys or rents the necessary equipment. Under favorable conditions this method may give excellent results but in general it leads to higher costs than contract work. If the work is to last for a long period so that, by the offering of steady employment, good men can be secured and if a well qualified superintendent is employed the results may be very satisfactory. However, except in special cases the force account or day-labor method of carrying on construction work should be avoided.

In *contract construction*, an individual or company called the contractor agrees to carry out the work for a stipulated compensation according to some form of contract as explained later. As a rule the contractor is experienced in construction work, he has at least the nucleus of an organization, and more or less equipment which will be of service on the work. If necessary, he may be held to the faithful performance of the work by a bond which will be forfeited in whole or in part, to protect the owner.

**Forms of Contract.** — There are three general forms of contract: the lump sum, the unit price, and the cost-plus, but there are many modifications of each of these general forms. Each has its advantages, its disadvantages, and its field of usefulness.

A *lump sum contract* is one in which the contractor agrees to complete the work according to the plans and specifications for a stated sum of money.

A *unit price contract* is one in which the contractor agrees to complete the work for a stated price per unit for each class of work. For example, on an excavating job a contractor may agree to do all of the earth excavation at a certain price per cubic yard and all of the rock excavation at another price per cubic yard.

A *cost-plus contract* is one in which the contractor agrees to complete the work for an amount equal to the cost of the work plus an allowance for his fee and for certain expenses which are not usually included in the cost. This allowance may be a fixed *percentage* of the cost as in cost plus percentage contracts; it may be a *sliding percentage* with a maximum fee, the percentage in any case depending upon the final cost of the work and decreasing as the cost increases; it may be a *fixed sum* as in cost plus a fixed fee contract; or it may be a varying amount which is larger if the work is completed at a low cost as compared with the estimate and smaller if the cost is high.

In any of the cost-plus forms of contract a maximum cost which the contractor guarantees will not be exceeded may be named. The contractor may guarantee this maximum and assume all of the cost above

that figure or he may guarantee it only to the limit of a certain part of his fee, say one-half.

The cost-plus contracts may also contain a profit-sharing provision whereby any saving from the estimated cost is divided between the owner and the contractor, the latter usually being assigned from one-third to one-half of such saving.

In all cost-plus contracts it is necessary to state clearly what costs are to be paid by the owner and upon what costs the fee is to be determined. It is customary to exclude the expenses of the contractor's main office, the salaries of those executives who spend only a part of their time on the job, and traveling expenses. These are to be paid by the contractor from his fee. The salaries and other expenses of the staff that the owner maintains on the job are usually excluded in figuring the contractor's fee.

**Field of Usefulness of Each Form.** — In general, each of the forms of contract has its distinct field of usefulness but special conditions may change the situation.

The lump sum contract is usually preferable when the complete plans and specifications are available, when no uncertain conditions are involved, and when material prices and wages are reasonably stationary.

The unit price contract finds its greatest field of usefulness on jobs where the kinds of work to be done are well understood and can be definitely specified, but the quantities are uncertain.

The cost plus a percentage contract is the only form which can be satisfactorily used when definite plans and specifications have not been prepared or cannot be prepared on account of the nature of the work, so the kind of work to be done is uncertain and the quantities cannot be determined. It is also a suitable form for use when economic conditions are greatly disturbed. In some cases it is desirable or necessary to let a contract before the plans and specifications have been completed. A cost plus a percentage contract may be used under these conditions.

The cost plus a fixed fee requires that the approximate magnitude of the work be known in order that an appropriate fee may be decided upon.

Cost-plus contracts involving guaranteed maximums and profit-sharing require that the plans and specifications be as complete and the conditions be as certain as with the lump sum contract.

**Advantages and Disadvantages of Each Form.** — The lump sum form of contract has two decided advantages: The owner knows before undertaking the work what the cost is going to be and can decide whether or not the expenditure will be justified; and low costs are secured because of the competition among the contractors to secure the work. Probably the chief disadvantage is the lack of elasticity of this form of contract when changes from the original plans are made. Such changes

require extras for additional work or credits for work omitted or simplified and it is in the adjustment of these extras and credits that the chief difficulty with lump sum contracts arises. This condition can be improved by stating in the contract the unit prices for the various classes of work likely to be encountered. However, all changes cannot be taken care of in this way. If plans and specifications are carefully prepared and rigidly adhered to there is no reason to fear the lump sum contract on account of the extras. Another disadvantage of the lump sum contract is that it makes the interests of the owner and the contractor conflict. There is a tendency on the part of the contractor to do the work as cheaply as possible and thereby make as much profit on the contract as he can. However, contractors have their reputations to make and maintain and as a rule they take a pride in their work, so this conflict of interest is not as serious as it might appear to be. Finally, lump sum contracts require that the plans and specifications must be complete before the contract is awarded.

The unit price contract is really a lump sum contract for each unit of work. As soon as the quantities of each kind of work are definitely established, the amount of the contract is definitely fixed. In such work as excavation or tunneling this form of contract has a distinct field of usefulness for when the kind of materials which will be encountered and the quantities of each are not known a unit price or each possible kind of material can be agreed upon and the quantities can be determined as the work progresses. However, considerable difficulty may arise in the classification of material which is on the border line between two classes mentioned in the contract. Plans and specifications need not be complete and the extent of the work need not be definitely decided upon in the unit price contract.

Where various kinds of work are involved in unit price contracts it is necessary to know the approximate quantity of each so that the low bid may be determined. These approximate quantities multiplied by the corresponding unit costs give values which when added will give the approximate total cost of the work by which the low bidder may be selected. A contractor may out-guess the engineer in his estimate of quantities and give a low unit price on work which the engineer has overestimated and a high unit price on the work which the engineer has underestimated. His total bid is therefore too low but the amount he is paid for his work may be excessive. Such bids are said to be *unbalanced.* Bids on unit price contracts may be unbalanced for other reasons, one of which is to secure high payments during the early part of the work. For instance, a contractor may name a high unit price for excavation and a low unit price for concrete for foundations to be placed in the excavation. In this

way he is paid more for the excavation than it is worth and gets the use of the additional money thereby secured. This practice becomes serious when the contractor withdraws from the job and leaves it to his bondsmen to complete on the balance due him. Evidence of unbalanced bidding is sufficient cause for the rejection of such bids.

The principal advantage of the cost plus a percentage form of contract is that it frees the contractor from any risk arising from uncertain weather conditions, unexpected difficulties which may arise particularly in excavation, changing prices, wages, etc. In other words, it takes gamble out of contracting and for this reason lower costs to the owner should in general be secured. This form of contract enables the owner to select a contractor before the plans and specifications have been completed and the work may start at once if desired. Often this is a decided advantage when the time element is important, although such action usually results in increased costs due to changes which have to be made as the plans are completed. Extras which are so objectionable in the lump sum form of contract are entirely avoided. There is no incentive for the contractor to slight the work to save money.

The main objection to the cost plus a percentage form of contract is that it does away with the incentive on the part of the contractor to do the work as economically as possible and encourages him to increase the cost for he is thereby increasing his fee. It is urged that employes always learn that they are working under a cost-plus contract and therefore do not work as hard as they would otherwise for by so doing they are exerting themselves less and are increasing their employer's profit. Under this form of contract the total cost is not known until the work is completed. It may be much greater than expected and thereby cause considerable difficulty to the owner in raising the money to complete the work and the investment required may be larger than would be warranted considering the return which may be expected. Such a condition is probably an extreme, however.

The cost plus a fixed sum does away with the incentive to increase the cost but does not provide an incentive for reducing costs. The latter is provided by the profit-sharing clause and also by the guaranteed maximum. However, as soon as these factors are introduced it is necessary to have complete plans and specifications and by restoring the gambling feature the most important advantages of the cost-plus method are lost.

Regardless of the objections urged against the cost-plus form of contract, this form of contract is extensively used and is considered a very desirable form of contract by many even though the plans and specifications for the work covered by the contract are complete and a lump sum contract could therefore be used. In most instances there is no competi-

tion in the cost-plus form of contract, the owner selecting his contractor on the basis of his reputation and experience. Competition can be secured on the basis of the fee to be charged or on the guaranteed maximum but this is not very satisfactory.

**Standard Documents.** — The American Institute of Architects has formulated contract documents to cover the usual forms of contract. These standard forms are very extensively used without any alterations whatever and in many cases where they do not exactly apply they form the basis of the contracts which are used. On important work even though the standard forms are used it is advisable to have legal advice in preparing the contracts. Copies of these documents may be secured for a nominal charge from the secretary of the Institute, Octagon Building, Washington, D. C.

**General Contractor and Subcontractor.** — Usually the contract for the construction of the entire building is awarded to a general contractor but frequently the contract for the plumbing and heating is let separately. The general contractor may carry on the entire work with his own forces, he may do only a part of the work such as the concrete and carpenter work and sublet the remainder to subcontractors for the various trades, or he may sublet all of the work. In any case the general contractor is the one with whom the owner has his dealings and whose bond the owner holds for the faithful performance of the work. The general contractor may, in turn, require a bond from each of his subcontractors. A common clause in specification states that the general contractor may not sublet any part of the work without the written consent of the owner but this clause is very generally ignored. A more satisfactory clause requires that a list of the subcontractors which a general contractor proposes to use be submitted with his bid. In this way the owner may protest against subcontractors whom he considers undesirable and if necessary refuse to award the contract to a general contractor whose subcontractors are considered unreliable.

Frequently the work to be done to complete a building is divided into various parts by the specifications so that each part such as concrete, brickwork, carpentry, etc., can be let directly to a subcontractor and in this way the services of a general contractor are dispensed with. However, the construction could not possibly proceed unless someone coordinated the work of the various subcontractors. This service is performed by the architect or engineer who thereby assumes the rôle of the general contractor, in fact if not in name, and is entitled to additional compensation because the burden he assumes is a heavy one.

In general, it is probably more desirable for a general contractor to sublet quite a large part of the work because he thereby secures advan-

tage of the organizations of the several subcontractors, of their ability as superintendents or foremen, and of their equipment. In this way a general contractor with a relatively small organization can carry on work which only the large organizations would be capable of doing with their own forces. Of course each subcontractor must have his profit and therefore in lump sum contracts a general contractor who does not subcontract the work might be able to submit a lower figure than that of a general contractor who depended entirely upon subcontractors. However, his overhead charges may offset this advantage. In cost-plus contracts a large part of the work is usually done by the general contractors. If the cost is simply to be the sum of all of the subcontractors' bids the whole spirit of the cost-plus idea has vanished. The subcontractors would be taking the gamble instead of the general contractor.

### REFERENCES

See the following papers and the discussion of these papers in the publications of the American Society of Civil Engineers.

Contracts — A Comparison of Cost Plus with Other Forms, by E. W. Clarke. *Transactions*, Vol. 83, p. 784.

General Contract System Versus Segregated Contracts, by W. P. Christie. *Proceedings*, February 1928 to August 1928.

Letting Construction Work by Competitive Bidding, by E. W. Bosh. *Proceedings*, November 1928 to March 1929.

## ARTICLE 91. BONDS AND INSURANCE

**Guaranty Bonds.** — Specifications usually state that the owner shall have the right to require that the contractor furnish bond which will guarantee the faithful performance of the contract and the payment of all obligations arising under the contract. A surety company bond is commonly required. The amount of the bond may be equal to the full amount of the contract but usually a bond equal to 40 or 50 per cent of the amount of the contract is considered as giving satisfactory protection. In any case, the premium is $1\frac{1}{2}$ per cent of the full contract price providing the contract is completed within two years. If not completed during that period an additional premium of three-quarters of one per cent must be paid for each additional year. Adjustments in the premium are made for changes in the contract price due to extras or deductions.

If a contractor fails to complete his work according to contract and the owner has to take over the work and complete it, the owner is protected by the surety company against any loss on account of the total cost exceeding the contract price.

**Employer's Liability Insurance.** — An employer is legally responsible for the injuries sustained by his employes while engaged on his work.

Before the workmen's compensation was introduced it was necessary for an injured employe to bring action in the courts against his employer to receive compensation for his injuries unless, of course, the employer was willing to make a satisfactory adjustment without such action being taken. It was necessary to prove in the courts that the injury was due to negligence on the part of the employer and not due to the carelessness of the employe himself or a fellow employe or that it was not an unavoidable accident for which no one was responsible. Such procedure was expensive on account of the lawyer's fees and other costs, was very slow, and had an undesirable effect on the relations between the injured employe and his employer. Under the liability insurance system an employer may protect himself against loss due to accidents to his employes by carrying employer's liability insurance by which the insurance company is required to defend all suits due to injuries to employes, to pay the costs of defense, and to pay any damages which may be awarded. Ordinarily employers' liability insurance policies have a $5000 limit where one person is injured and $10,000 for one accident in which two or more persons are injured. Limits larger than these can be obtained by paying increased premiums. The amount of the premiums is based on the size of the payroll and the danger involved in the work being done. The premium may be as low as 1 per cent of the payroll for a safe occupation such as carpentry and as high as 20 per cent for structural steel erectors.

**Workmen's Compensation.** — Workmen's compensation legislation fixing the compensation to be paid an employe in case of injury regardless of where the responsibility lies, has been enacted by all of the states except Arkansas, Florida, Mississippi, Missouri, North Carolina, and South Carolina, and the District of Columbia. Workmen's compensation is a great improvement over the employer's liability doctrine. The compensation which an injured person receives depends upon the loss of earning capacity and the amount of the loss of income and is specifically provided for. It no longer depends upon the judgment of a court. The compensation laws are administered by commissions and the services of lawyers are not usually required.

In most states, employers are required by law to provide for workmen's compensation by taking out insurance. Where such a requirement is not made but the taking out of insurance is optional with the employer his legal defenses are so curtailed that his position in court is greatly weakened. In some states where compensation laws have been enacted the employer is required to carry his insurance with the state but other states permit insurance companies to function, with the competition of the state in some states, and without in others.

Accidents are classified according to the severity of the injury, ranging from partial disability, which is only temporary, to permanent total disability and death. The compensation is usually a specified percentage of the employe's weekly earnings and depends upon the degree of disability.

The rates for workmen's compensation insurance depend upon the hazard of the occupation and vary from about 1 per cent for the safer occupations in some states to as high as 27 per cent for structural steel erectors.

Reports of accidents must be made promptly by the employer to the compensation commission to whom the injured employee makes application for compensation.

**Contingent Liability Insurance.** — A contractor should require that all of his subcontractors protect themselves and him by carrying such compensation or other insurance as is necessary. In order to make certain that this has been done it is good practice to require that each subcontractor file with the contractor a certificate from the insurance company before the work is started.

Since the contractor is required to protect the owner against damages from whatever cause resulting from the carrying out of the contract it may be necessary for him to protect himself against accidents which are not covered by the workmen's compensation or employer's liability insurance carried by his subcontractors or by himself.

**Public Liability Insurance.** — This form of insurance is for the purpose of providing protection of an owner against the payment of damages due to the injury to persons other than employes and which may be attributed to his work.

**Fire Insurance.** — The owner is usually required by the contract to maintain fire insurance on the building itself and the materials in or adjacent to the building and intended for use in the building. If he fails to do so, the contractor may carry such insurance and charge the cost to the owner. If the contract does not make this provision and if the owner does not carry fire insurance it is desirable for the contractor to carry sufficient insurance to cover the difference between the payments he has received and the cost of the work he has completed.

**Other Forms of Insurance.** — There are many other forms of insurance in connection with building construction which give protection from damages due to accidents with elevators, automobiles, steam boilers, and teams. Other forms are: Property damage insurance, which protects against damages to the property of others due to the building operations; tornado insurance; pay-master robbery insurance; and safe burglary insurance.

## CHAPTER XVII

# COST KEEPING, TIME SCHEDULES, PROGRESS CHARTS AND COST CHARTS

### ARTICLE 92. COST KEEPING

**Definition.** — Cost keeping has been defined as a system for recording the cost of each unit of product or division of work in order to facilitate comparison of such costs with the cost of other similar units or divisions under like conditions. Cost keeping analyzes each unit of product or work to determine the reasonableness or unreasonableness of the cost, and also to secure an intelligent basis for predicting the cost of producing similar units in the future.[1]

**General Discussion.** — The growth of cost keeping in the manufacturing industries has been quite rapid but on account of the greater complexities of construction work many contractors and engineers have been slow in taking advantage of this relatively recent development in accounting practice. A cost-keeping system may be so designed as to yield unit costs daily, weekly, or at any other interval. Daily reports of labor unit costs are often essential on certain parts of building construction such as concrete, brickwork, and concrete forms, but weekly reports may suffice. The unit costs thus obtained are compared with the estimated unit costs in order that every effort may be exerted to reduce immediately any costs which are running too high. If the actual cost cannot be kept within the estimate it is then evident that the estimated cost was too low and should be increased on future work. Material unit costs need not be as frequent or as prompt as labor unit costs for there is much less opportunity for wasting materials than for wasting labor and the waste of material is more evident to a superintendent than the waste of labor. Everyone on a job may be working to his utmost and still the cost may be excessive due to the use of uneconomical methods. A careful analysis of unit costs may disclose faulty methods which appear to be entirely satisfactory. It is desirable to keep a daily record of the amount of cement used per cubic yard of concrete as cement is a material which can easily be wasted without such waste being evident from inspection.

In addition to yielding unit costs, a cost-keeping system must provide data for weekly or monthly reports showing the financial status of the job. Such reports should indicate how much each branch of the work is

[1] Bulletin 660. U. S. Department of Agriculture, by J. J. Tobin and A. R. Losh.

overrunning or underrunning the estimate and how the total cost to date compares with the estimate for the work done to date.

Cost records may be kept in terms of hours of labor and quantities of material per unit of product instead of yielding actual costs. Such unit costs can be used directly for estimating new work whereas actual unit costs must be corrected for the change in the wage scale and material prices. Either method may be made to yield satisfactory results but the use of actual costs is much the more common. In recording unit costs the labor cost and material cost should be kept separate and if overhead and plant charges are included they should also be kept separate.

It is very important that suitable units be adopted in determining unit costs. For instance, the cost of forms for concrete work should be given in terms of the number of square feet of forms in contact with the concrete and not in terms of the number of cubic yards of concrete contained in the forms as is so often done.

The number of square feet of forms in contact with the concrete is a fairly good measure of the quantity of lumber to be provided and placed but this quantity is only remotely related to the number of yards of concrete contained in the forms. A wall one foot thick will require practically the same amount of material for the forms as a wall three feet thick so the cost of forms per cubic yard of concrete will be three times as great for the one-foot wall as for the three-foot wall. The cost per square foot of forms in contact with the concrete will be practically the same. Cost keeping has an entirely different function from bookkeeping and does not lessen the need for an efficient bookkeeping system.

Cost-keeping systems assume a great variety of forms depending upon the type of organization, the methods of securing data, the information to be secured, and the personal preferences of those responsible for the systems. However, they all possess certain essential features about as follows:

(*a*) The work must be subdivided into logical classes or accounts such as excavation, concrete work, etc.

(*b*) Each class or account must be given a symbol, for convenience.

(*c*) The labor cost records must distribute the expenditures for labor to the proper account.

(*d*) The material cost records must charge all material costs to the proper account.

(*e*) The quantity of each class of work accomplished during the current period and to date must be reported.

(*f*) From (*c*) and (*d*) the total material and labor cost for the current period and to date are obtained for each class of work. From (*e*) the quantity of work done during the current period and the quantity fin-

ished to date are obtained. From this information a report is prepared showing the unit cost for the current period for each class of work and the unit cost to date as compared with the estimated unit cost.

(*g*) From the same data as required in (*f*), a report is prepared showing the total cost of each class of work during the current period, the total cost of each class to date, and the saving or loss as compared with the estimate for each class of work for the period and to date. The total of these savings and losses to date shows the status of the job to date. This report is sometimes extended to show what the saving or loss on the completed job will be if the work continues at the present unit costs.

(*h*) A final cost summary is made when the job is completed. This gives all of the pertinent cost information concerning the work.

(*i*) A record may be made of the production per man-hour for each class of work to which this unit may be applied. This record is for use in estimating future work and is more convenient than the unit labor cost on account of changes in the scale of wages.

(*j*) Construction companies which are carrying on several jobs at once often prepare a weekly or monthly statement showing the financial status of each of the jobs under way. Such reports may show the cost of each job to date, the overrun or saving on each job for the current period as compared with the estimates, the overrun or saving on each job to date, and the estimated profit or loss on each job when completed if current unit costs are maintained.

**Classification of Accounts.** — The first step in devising a cost-keeping system is the dividing of the various items of cost into logical groups according to the nature of the work such as excavation, concrete work, brick work, rough carpentry, etc. Each of these main groups is then subdivided to any degree desired. In preparing the estimate for a job, the classification used in the cost-keeping system should be followed to a sufficient extent that the actual and estimated costs may be readily compared.

**Symbols for Accounts.** — In order to save time in recording and space on the forms used for recording it is very essential that the accounts be designated by symbols. These may be either numbers or letters or a combination of the two. If letters are used they may be chosen arbitrarily or they may be mnemonic so that the letter will indicate the kind of work, for example, *B* for brick work, *C* for concrete, etc. Numerical systems are often patterned after the decimal system used in the classification of books in libraries. The decimal system has the advantage of being very elastic. Many claim that a mnemonic system has the distinct advantage of being easily remembered but there is little difficulty with any logical system from this point of view.

The following system of account numbers illustrates the use of the decimal system:

Classification of Accounts

| | |
|---|---|
| *0–9* | Job Overhead and Plant Charges |
| *10–19* | Excavation |
| *20–29* | Concrete |
| *30–39* | Waterproofing |
| *40–49* | Masonry |
| *50–59* | Concrete Forms |
| *60–69* | Rough Carpentry |
| *70–71* | Finish Carpentry |
| *80–81* | Lathing and Plastering |
| *90–91* | Roofing |
| *100–101* | Glass and Glazing |
| *110–119* | Painting and Decorating |
| *120–129* | Sheet Metal Work |
| *130–139* | Reinforcing Steel |
| *140–149* | Structural Steel |
| *150–159* | Ornamental Iron |
| *160–169* | Hardware |
| *170–179* | Plumbing and Gas Fitting |
| *180–189* | Heating and Ventilating |
| *190–199* | Electric Wiring |
| *200–209* | Mechanical Equipment |

It will be noted that the numbers are arranged in groups of ten. The numbers in each group are allotted to branches of the work which logically fall in that group on account of the similarity of the work. Each group is subdivided into the number of accounts necessary to include all parts of the work. If ten numbers are insufficient for any group, twenty or thirty may be assigned to that group. As an illustration of the method of subdivision the group *20–29*, *Concrete*, is expanded as follows:

*20* Concrete Footings
*21* Concrete Foundation Walls
*22* Plain Concrete Floors
*23* Plain Concrete Walks and Drives
*24* Plain Concrete Curb and Gutter
*25* Reinforced-concrete Floors and Roofs
*26* Reinforced-concrete Stairs
*27* Concrete Lintels
*28* (Unassigned)
*29* Miscellaneous Concrete

Other groups are expanded in a similar manner.

Each general account is further subdivided by numbers to the right of the decimal point, the accounts containing *.1* being labor accounts and those containing *.2* being material accounts, and if desired the accounts containing *.3* may be used for plant charges or overhead. The labor and material accounts can be subdivided to any extent desired. The accounts ending in *9* are usually reserved for miscellaneous charges. For instance, *.19* is used for miscellaneous labor and *.29* miscellaneous material. This method of subdivision is illustrated below. The accounts ending in *.21* and *.22* are used for cement and sand in all parts of the work where these materials are used. For instance, *20.21* and *20.22* are the account numbers for cement and sand used in concrete footings and *41.21* and *41.22* are the corresponding account numbers for brick masonry. Further subdivision can be secured by using three digits to the right of the decimal, thus, *.111*, *.112*, etc. The method of subdivision may be illustrated by Account *25* as follows:

*25*. Reinforced-concrete Floors and Roofs
- *.11* Mixing and Placing
- *.12* Setting runways, building cutoffs
- *.19* Miscellaneous Labor
- *.21* Cement
- *.22* Sand
- *.23* Coarse Aggregate
- *.29* Miscellaneous Material

The main division might have been numbered *A*, *B*, *C*, etc., instead of *0–9*, *10–19*, *20–29*, etc., with the subdivision numbered *A-1*, *A-2*, *A-3*, etc. A partially mnemonic system might be devised by using *O* for Job Overhead accounts, *E* for Excavation, *C* for Concrete, etc. Further subdivision can be secured by adding second and third numbers or letters.

The Aberthaw Construction Company of Boston has a unique mnemonic code for labor accounts. The first letter is always a capital and indicates the kind of work to be done. For instance —

*F* stands for Forms
*R* stands for Reinforcement
*B* stands for Brick
*D* stands for Digging

The first letter of the item is used whenever possible. The second letter is always a vowel and explains the class of work as follows:

*a* stands for making items
*e* stands for erecting or setting up
*i* stands for tearing down or dismantling
*o* stands for repairing
*u* stands for unloading, etc.

The third letter, which is always a consonant, indicates the part of the building in which the work is being executed, as —

*f* stands for floors
*w* stands for walls
*c* stands for columns
*s* stands for stairs

The symbol *Bew* would indicate Brick, erect, walls, i.e., erecting brick walls. *Fas* stands for making stair forms; *Fes*, erecting stair forms; *Fis*, stripping stair forms.

**Labor Distribution.** — In any cost-keeping system it is necessary to obtain a record of the specific piece of work on which each employe is engaged and the kind of work he is doing. Such data must be secured in addition to the information usually secured by the timekeeper who is concerned only with the amount of time and not its distribution, except in a general way. The timekeeper may be charged with the securing of this additional information or the information may be furnished by the foremen.

The Timekeeper's Field Sheet shown on p. 527 is used by the Aberthaw Construction Company[1] to record the labor distribution. By consulting this sheet it is seen that the time of the man whose number was *2221* was chargeable to account *Raz* from 7 to 11 A. M. From 11 to 12 A. M. and from 1 to 5 P. M. his time was chargeable to account *Ref*. The time of starting work in the morning and in the afternoon are given, the time of quitting, the rate of pay, the total time for the day, and the amount earned are also given. In securing this information the timekeeper makes four trips over the work each day. If an employe has been shifted between trips, the time of shifting, to the nearest hour, is secured from the foreman.

The Thompson-Starrett Company of New York secures the labor distribution from the foremen's reports as shown on p. 528. The total for each report for each day must check with the timekeeper's total but the timekeeper's records do not show the distribution. Account numbers are not usually used by the foremen. Their reports merely report the kind of work, its location, and the number of hours each man spent on each piece of work. These records are put in more usable form and summarized in the office.

The labor distribution obtained from the daily time sheets is summarized for the week by the Aberthaw Company on the "Waste Sheet" shown on p. 529. This sheet shows the total to charge to each account

[1] Construction Costs by W. N. Connor. Journal of Boston Society of Civil Engineers, May, 1921.

ABERTHAW CONSTRUCTION COMPANY

Job No. — *1175* | Date — *12-27-19*

TIMEKEEPER'S FIELD SHEET

At — *Torrington, Conn.* | Timekeeper — *H. W. Murdick* | Sheet No. — *1*

| Man's No. | | In A.M. | In P.M. | Out | 7–8 | –9 | –10 | –11 | –12 | 1 P.M. | –2 | –3 | –4 | –5 | –6 | Rate | Am't. | Time Reg. | Time Over. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *2201* | | | | | | | | | | | | | | | | | | |
| *Kinsley* | *2* | *7* | .... | *5* | *0* | .. | .... | .... | .... | .... | .... | .... | .... | .. | .. | *39.00* | *6.50* | *9* | |
| | *3* | | | | | | | | | | | | | | | | | | |
| | *4* | | | | | | | | | | | | | | | | | | |
| *Hollen* | *5* | *7* | .... | *5* | *Raf* | .. | .... | *Raz* | .... | .... | *Ref* | .... | *Rec* | .. | .. | *40.00* | *6.67* | | |
| *Howard* | *6* | *7* | .... | *5* | *Fec* | .. | *Fed* | .... | .... | .... | .... | *Few* | .... | .. | .. | *48.00* | *8.00* | *9* | |
| | *7* | | | | | | | | | | | | | | | | | | |
| *Murdick* | *8* | *7* | .... | *5* | *0* | .. | .... | .... | .... | .... | .... | .... | .... | .. | .. | *21.00* | *3.50* | *9* | |
| | *9* | | | | | | | | | | | | | | | | | | |
| | *2210* | | | | | | | | | | | | | | | | | | |
| *Zavrello* | *11* | *7* | .... | *5* | *Dad* | .. | .... | *Mux* | .... | .... | *Mef* | .... | *Ded* | .. | .. | *39.00* | *6.50* | *9* | |
| | *12* | | | | | | | | | | | | | | | | | | |
| | *13* | | | | | | | | | | | | | | | | | | |
| | *14* | *7* | .... | *5* | *Fec* | .. | *Few* | .... | .... | .... | *Fed* | .... | .... | .. | .. | *.85* | *7.65* | *9* | |
| | *15* | *7* | .... | *5* | *Fef* | .. | .... | .... | .... | .... | .... | .... | .... | .. | .. | *.85* | *7.65* | *9* | |
| | *16* | *7* | .... | *5* | *Fec* | .. | *Few* | .... | .... | .... | *Fed* | .... | .... | .. | .. | *.85* | *7.65* | *9* | |
| | *17* | *7* | .... | *5* | *Fef* | .. | .... | .... | .... | .... | .... | .... | .... | .. | .. | *.85* | *7.65* | *9* | |
| | *18* | *7* | .... | *5* | *Fec* | .. | .... | .... | .... | .... | *Fed* | .... | .... | .. | .. | *.85* | *7.65* | *9* | |
| | *19* | *7* | .... | *5* | *Fec* | .. | .... | .... | .... | .... | *Fed* | .... | .... | .. | .. | *.85* | *7.65* | *9* | |
| | *2220* | | | | | | | | | | | | | | | | | | |
| | *21* | *7* | .... | *5* | *Raz* | .. | .... | .... | *Ref* | .... | .... | .... | .... | .. | .. | *.55* | *4.95* | *9* | |
| | *22* | *7* | .... | *5* | *Raz* | .. | .... | .... | *Ref* | .... | .... | .... | .... | .. | .. | *.55* | *4.95* | *9* | |
| | *23* | *7* | .... | *5* | *Rec* | .. | *Raf* | .... | .... | .... | *Ref* | .... | .... | .. | | *.55* | *4.95* | *9* | |
| | *24* | *7* | .... | *5* | *Rec* | .. | *Ref* | .... | .... | .... | .... | .... | .... | .. | .. | *.55* | *4.95* | *9* | |
| | *25* | | | | | | | | | | | | | | | | | | |
| | *26* | *7* | .... | *5* | *Mef* | .. | .... | *Ref* | .... | .... | .... | *Mh* | .... | .. | .. | *.70* | *6.30* | *9* | |
| | *27* | *7* | .... | *5* | *Pel* | .. | *Pem* | .... | .... | .... | *Mh* | .... | .... | .. | .. | *.70* | *6.30* | *9* | |
| | *28* | *7* | .... | *5* | *Mh* | .. | .... | .... | .... | .... | .... | .... | .... | .. | .. | *.70* | *6.30* | *9* | |
| | *29* | | | | | | | | | | | | | | | | | | |
| | *2230* | | | | | | | | | | | | | | | | | | |
| | *31* | | | | | | | | | | | | | | | | | | |
| | *32* | *7* | .... | *5* | *Mux* | .. | .... | .... | *Muy* | .... | .... | .... | .... | .. | .. | *.50* | *4.50* | *9* | |
| | *33* | *7* | .... | *5* | *Mux* | .. | .... | *Mef* | .... | .... | .... | .... | .... | .. | .. | *.50* | *4.50* | *9* | |
| | *34* | *7* | .... | *5* | *Mux* | .. | .... | *Mef* | .... | .... | .... | .... | .... | .. | .. | *.50* | *4.50* | *9* | |
| | *35* | *7* | .... | *5* | *Mux* | .. | .... | .... | *Muy* | .... | .... | .... | .... | .. | .. | *.50* | *4.50* | *9* | |
| | *36* | .... | *1* | *5* | .... | .. | .... | .... | .... | .... | *Mef* | .... | .... | .. | .. | *.50* | *4.50* | *4* | |
| | *37* | *7* | .... | *5* | *Dad* | .. | .... | *Mef* | .... | .... | .... | .... | .... | .. | .. | *.50* | *4.50* | *9* | |
| | *38* | *7* | .... | *5* | *Dad* | .. | .... | *Ded* | .... | .... | .... | .... | .... | .. | .. | *.50* | *4.50* | *9* | |
| | *39* | *7* | .... | *5* | *Dad* | .. | .... | *Ded* | .... | .... | .... | .... | .... | .. | .. | *.50* | *4.50* | *9* | |
| | *2240* | | | | | | | | | | | | | | | | | | |
| | *41* | | | | | | | | | | | | | | | | | | |
| | *42* | | | | | | | | | | | | | | | | | | |
| | *43* | | | | | | | | | | | | | | | | | | |
| | *44* | | | | | | | | | | | | | | | | | | |
| | *45* | | | | | | | | | | | | | | | | | | |
| | *46* | | | | | | | | | | | | | | | | | | |
| | *47* | | | | | | | | | | | | | | | | | | |
| | *48* | | | | | | | | | | | | | | | | | | |
| | *49* | | | | | | | | | | | | | | | | | | |
| | *50* | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | $ | *149.27* | *229* | |

each week. The total of the charges to all accounts for each week must check with the weekly payroll. On this sheet also appears the quantity of work done. Knowing the total labor charge to each account for each week and the quantity of work done each week, the unit labor costs are readily secured. The information concerning the quantities is furnished by the quantity man.

### FOREMAN'S DAILY REPORT

THOMPSON-STARRETT COMPANY

____________BUILDING__________JOB NO._____DATE_______192_

FOREMAN

| Quantity Work Done | Sub-division | Description Work Done | No. Men | Hours | | | Rate | Remarks |
|---|---|---|---|---|---|---|---|---|
| | | | | Excess | Actual | Total | | |
| | | | | | | | | |
| | | | | | | | | |
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CHECKED BY________________

TIMEKEEPER

**Labor Cost Reports.** — The information given on the Waste Sheets is arranged in more usable form on the Labor Cost Record illustrated on p. 530. There is one sheet for each account or symbol. This record gives the weekly cost, the weekly quantity, the weekly unit cost, the total cost to date, the quantity to date, the unit cost to date, and in the

Job No.—*1175* WASTE SHEET Week Ending—*1-6-20*

| Date | Dad | Dadp | Dedp | | Fec | Fic | Facw | Fecw | Fad | Fed | Fef | Fif | Fecb | Fewb | Fiwb | | Gew | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12-31-19 | 10.25 | 77.90 | | | 30.00 | 12.00 | | 8.40 | | 17.95 | 74.95 | 32.00 | | 12.48 | 8.25 | | 8.50 | | | |
| 1-1-20 | | 55.55 | 7.40 | | 32.85 | 15.45 | | 7.65 | | | 82.10 | 31.50 | 14.50 | 14.50 | 12.00 | | 8.50 | | | |
| 1-2-20 | | 59.20 | 9.00 | | 27.50 | 17.20 | | 9.20 | | | 78.80 | 31.99 | | 12.00 | 10.30 | | 10.20 | | | |
| 1-3-20 | 6.00 | 60.63 | | | 30.42 | 14.85 | 7.35 | 6.85 | | | 69.03 | 33.60 | | 11.05 | 5.75 | | 9.75 | | | |
| 1-4-20 | | | | | | | | | | | | | | | | | | | | |
| 1-5-20 | | 75.85 | 5.40 | | 27.58 | 19.00 | | 5.00 | | | 80.15 | 29.00 | | 9.00 | 8.25 | | 9.75 | | | |
| 1-6-20 | | 61.00 | | | 26.00 | 12.60 | | 6.45 | 10.25 | | 80.00 | 32.10 | | 17.50 | 1.00 | | 6.38 | | | |
| Total | 16.25 | 390.13 | 21.80 | | 174.35 | 91.10 | 7.35 | 43.55 | 10.25 | 17.95 | 465.03 | 190.19 | | 76.53 | 45.55 | | 53.08 | | | |
| Quantity | 8 c.y. | 240c.y. | 61c.y. | | 16.2 sq. | 25.6 sq. | 1.2 sq. | 4.2 sq. | 1.9 sq. | 1.9 sq. | 90.5 sq. | 70.7 sq. | | 74 sq. | 15.7 sq. | | 220s.y. | | | |
| Unit | 2.03 | 1.63 | .36 | | 10.75 | 3.57 | 6.15 | 10.35 | 5.51 | 9.65 | 5.14 | 2.69 | | 10.30 | 2.90 | | .24 | | | |

| Date | Mecw | Med | Mef | Mh | Muy | | O | | Pe | Pel | | Rac | Rec | Raf | Ref | | Sefp | Sev | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12-31-19 | | 4.10 | 141.61 | 50.30 | | | 15.41 | | 7.70 | 3.50 | | 5.06 | 11.45 | 8.40 | 27.43 | | | 15.60 | | 583.24 |
| 1-1-20 | 18.50 | 3.00 | 168.14 | 54.90 | | | 15.41 | | | 8.00 | | 4.23 | 12.16 | 9.23 | 31.80 | | 9.75 | | | 617.12 |
| 1-2-20 | 9.00 | 4.60 | 176.23 | 53.10 | 11.00 | | 15.41 | | | 2.00 | | 5.73 | 9.81 | 8.80 | 24.10 | | | | | 585.17 |
| 1-3-20 | 2.50 | 1.55 | 86.04 | 48.60 | | | 15.41 | | | 2.00 | | 7.10 | 10.42 | 10.15 | 29.48 | | | 6.29 | | 474.82 |
| 1-4-20 | | | | | | | | | | | | | | | | | | | | |
| 1-5-20 | | 4.60 | 93.22 | 61.33 | | | 15.41 | | | 1.00 | | 3.10 | 8.63 | 9.41 | 32.46 | | 11.40 | | | 509.54 |
| 1-6-20 | | | 40.72 | 62.65 | | | 15.41 | | | | | 2.20 | 15.60 | 7.26 | 15.33 | | | | | 412.45 |
| Total | 30.00 | 17.85 | 705.96 | 330.88 | 11.00 | | 92.46 | | 7.70 | 16.50 | | 27.42 | 68.07 | 53.25 | 160.60 | | 21.15 | 21.89 | | 3182.34 |
| Quantity | 14 c.y. | 7 c.y. | 218c.y. | | 98 c.y. | | | | | | | 8 T | 9 T | 11 T | 18 T | | | 700 lb. | | |
| Unit | 2.14 | 2.55 | 3.24 | | .112 | | | | | | | 3.43 | 7.56 | 4.84 | 8.92 | | | .031 | | |

Payroll for week ending — *1-6-20* $3182.34

case of concrete work, the number of barrels of cement used each week and the cubic feet of concrete obtained each week per barrel of cement. At the top of the sheet are given the estimated cost, the estimated quantity, and the estimated unit cost. The actual unit cost obtained each week is readily compared with the estimated unit cost, and when the work is completed the amount of saving or overrun for each account is readily obtained. These Labor Cost Records for all accounts on each job are assembled in a book and retained in the main office upon the completion of the job.

ABERTHAW CONSTRUCTION COMPANY

Job No. *1175* LABOR COST RECORD Symbol — *Med*

| | ESTIMATED | | | | | |
|---|---|---|---|---|---|---|
| | Cost | Quantity | Unit | | | |
| Item—*Concrete Footings & Piers* | *444.00* | *306 c.y.* | *1.45* | | | |

| Week Ending | Weekly Cost | Weekly Quantity | Weekly Unit | Total Cost | Quantity to Date | Unit to Date | Bbls. Cement | Cu. Ft. to Bbl. |
|---|---|---|---|---|---|---|---|---|
| *11-25-19* | *117 90* | *117 c.y.* | *1.01* | | | | *194* | *16.3* |
| *12-2-19* | *251 96* | *120 "* | *2.10* | *369 86* | *237 c.y.* | *1.56* | *198* | *16.3* |
| *12-9-19* | *72 27* | *42 "* | *1.72* | *442 13* | *279 "* | *1.23* | *69* | *16.4* |
| *12-16-19* | *9 97* | *6 "* | *1.66* | *452 10* | *285 "* | *1.59* | *10* | *16.2* |
| *1-6-20* | *17 85* | *7 "* | *2.55* | *469 95* | *292 "* | *1.61* | *12* | *15.7* |
| *1-13-20* | *4 86* | *2 "* | *2.43* | *474 81* | *294 "* | *1.62* | *4* | *13.5* |
| *1-20-20* | *12 70* | *10 "* | *1.27* | *487 51* | *304 "* | *1.60* | *17* | *15.8* |

The Weekly Labor Cost Statement as employed by the Aberthaw Construction Company is shown on p. 531. On this statement are indicated for each account the quantity done to date, the estimated unit cost, actual unit cost, estimated cost of the work done to date, the actual cost of the work done to date, and finally, the saving or overrun on each group of items such as excavation, concrete, etc. By examining this statement the superintendent can determine what parts of the work are going satisfactorily and what parts need attention. He can often turn a loss into a profit by giving timely attention to parts of the work where money is being lost, but if such a statement was not available he would not be aware of the unsatisfactory state of affairs until it was too late to seek a remedy. A similar form can be devised to include material costs.

**Materials.** — The cost of all materials purchased for each job is recorded in the Material Cost Record which provides a page for each material item shown on the estimate. This record contains all of the

amounts paid for material on the job and the total of this record and the labor cost record at the completion of the work must check with the total cost as shown in the bookkeeper's ledger.

ABERTHAW CONSTRUCTION COMPANY

Job. No. *1175* LABOR STATEMENT Sheet No. *1*

To *December 23, 19—. 8th Week.*

| Item | | | Quantity | | Unit | | Cost | | Saving | Overrun |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Est. | Actual | Est. | Actual | Est. | Actual | | |
| | *EXCAVATION* | | | | | | | | | |
| *Das* | *Clear site* | *$* | *100* | | | | *83* | *83* | | |
| *Dad* | *Dig footings* | *c.y.* | *800* | *702* | *1.70* | *1.35* | *1193* | *948* | | |
| *Ded* | *Backfill* | *c.y.* | *950* | *331* | *.83* | *.54* | *275* | *179* | | |
| *Dadp* | *Dig pipe trenches* | *c.y.* | *1030* | *931* | *1.70* | *1.48* | *1583* | *1378* | | |
| *Dedp* | *Backfill pipe trenches* | *c.y.* | *980* | *442* | *.83* | *.52* | *367* | *230* | | |
| | *Total* | | | | | | *3501* | *2818* | *683* | |
| (All items are listed but are omitted in this illustration.) | | | | | | | | | | |
| | *Total to date* | | | | | | *9336* | *8960* | *773* | *397* |
| | *Net saving or overrun to date* | | | | | | | | *376* | |

A Materials Cost Statement is prepared weekly or monthly so that the actual cost of materials can be compared with the estimated cost. The Aberthaw Construction Company does not have symbols for material accounts. If such a system is being used each invoice is distributed to the various accounts according to the part of the work on which the material is to be used. Such materials as cement, which may be used in various parts of the work, may be charged to a *stores account*, the charges to the specific accounts being made as the material is used. As previously stated, it is desirable to keep a daily record of the cement used per cubic yard of concrete, for cement may be wasted without the waste being apparent.

Material received on the job is checked and reported to the office on a Receiving Memorandum by the material clerk, a foreman, the timekeeper, or the superintendent, depending upon the organization.

**Final Cost Summary.** — After the job is completed a Final Cost Summary is prepared. The labor, material, and plant unit costs are shown separately and the total unit cost and the total cost are given. A copy of this report is given to the estimating department.

A Job History is attached to this report. This history gives all of the information which may be of future interest such as the personnel of the force employed, prices paid for materials, wages paid, list of subcontractors, nature of the soil and methods of construction.

## ARTICLE 93. TIME SCHEDULES, PROGRESS CHARTS, AND COST CHARTS

**Time Schedules.** — Time is an important factor in building construction. From the contractor's point of view it is desirable to complete a job promptly for many reasons, two of the more important being the saving in overhead costs such as superintendent's salary, watchman's wages, and other items of job overhead and the desirability of releasing equipment and men for use on other work. Progress which is so rapid as to require a considerable amount of overtime on the part of the employes is, of course, uneconomical on account of the higher rate paid for overtime. Each job has its most economical period for construction. From the owner's point of view, the sooner he is able to occupy a building the smaller will be the expense to him due to interest on the money tied up in the building during construction, and the taxes and insurance during the period when the building is not revenue producing, but a more important factor than these is probably that of convenience.

Contracts commonly carry a clause requiring that a building be completed by a certain date or that damages be paid. In many cases such clauses cannot be enforced due to the way they are worded or due to changes in the plans making them void. However, such clauses can be made effective.

Since it is desirable that buildings be completed with reasonable promptness, it is worth while to adopt such measures as will accomplish this end. One factor which will assist in doing this is the *time schedule*. This schedule is prepared before the building is started and consists of establishing a date on which each part of the work is to be started and a date for its completion so that it will fit in with all other parts of the work in such a way as not to interfere with other work by being undertaken too soon or delay other work by being completed too late. This requires that orders for material be placed in time to secure the desired delivery dates and that the necessary mechanics be available. The promise of delivery is not a sufficient guarantee of performance so that the matter can be dismissed from the mind of the one who is responsible for delivery. He must follow up the orders to see that they are progressing satisfactorily through the various shops which are to make the delivery. It is frequently desirable to follow the goods in transit to make sure that there are no delays along the way. Contractor's organiza-

tions sometimes include a man known as an *expeditor* to look after such matters.

A form of time schedule which is sometimes used is arranged as follows:

Time Schedule

| Item | Start | Finish |
|---|---|---|
| Item A | Aug. 1 | Aug. 15 |
| Item B | Aug. 5 | Sept. 1 |
| Item C | Aug. 10 | Sept. 15 |
| Item D | Aug. 12 | Sept. 10 |
| Item E | Aug. 4 | Sept. 30 |

Instead of the designations Items A, B, C, etc., appearing on the schedule, the actual work to be done is given, such as, Excavation, Concrete Footings, etc. All of the classes of work to be done on a building are included. The preparation of such a schedule requires extensive building experience.

**Progress Charts.** — The progress which is being made on a given piece of work is indicated graphically by means of *progress charts.* A simple form of progress chart is illustrated in Fig. 164, which shows the progress made each month on the excavation, piling and concrete of a concrete bridge. The work done each month is indicated by shading the corresponding part of the drawing with the cross-hatching which is chosen to represent the month.

Another form of progress chart as shown in Fig. 165*a* combines the time schedule and the progress chart. The time is indicated by the horizontal distances on the chart, each week end being indicated by a vertical line. The various items of work are listed in the column on the left side of the chart. The time which should be occupied by the construction of each item is indicated by a long blank space as shown on the figure. For instance, work on Item A is scheduled to begin on July 20 and to be completed on August 4. When work is started on a given item on time the blank is filled in with black beginning at the left end of the blank and extending to the right a distance which represents the ratio of the amount of work done at the date of the report to the total amount of work to be done as represented by the entire blank space. The progress chart for August 13 is shown in Fig. 165*b*. On that date Item A had been completed, Item B was up to schedule as the amount of work done was exactly in proportion to the time which had elapsed, Item C was about two days behind schedule and Item D about one day ahead of schedule. When a part of the work is late in starting the blank is cross-

hatched up until the time when it is started. Beginning at the date of starting the remainder of the blank is divided according to the ratio the amount of work done bears to the time remaining for completion. Work on Item E was begun on August 2 instead of July 26 as scheduled. On August 13 the work on this item was two days behind the schedule required to complete it on August 25 as planned. Instead of using

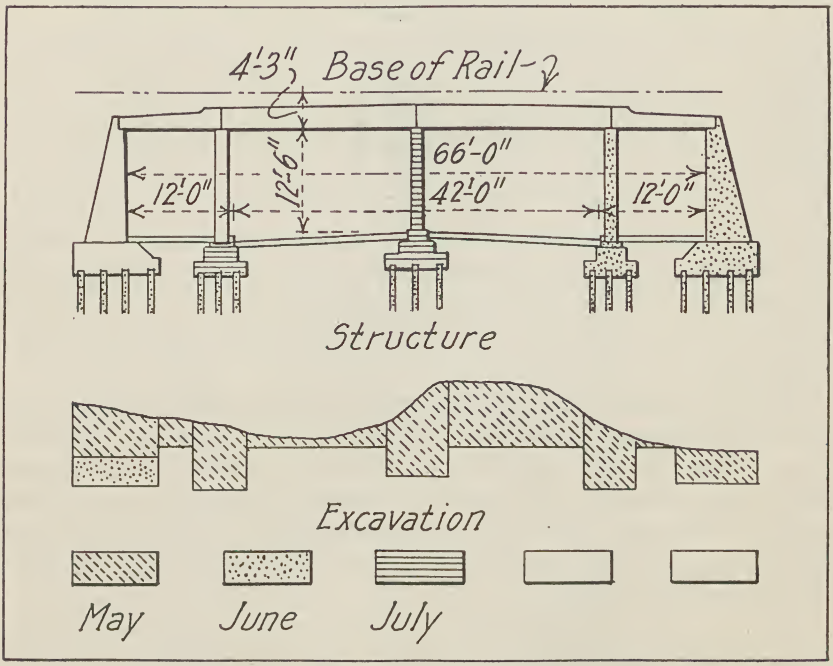


FIG. 164. Progress Chart of a Bridge

black and cross-hatching, colors may be used. The idea in this form of chart is that used by the Aberthaw Construction Company on some of its work.

A combined Time Schedule and Progress Chart is shown in Fig. 166. This type of chart applies only to such items as erecting the structural frame and the placing of the partitions where the progress may be measured by the number of stories completed. By consulting this chart it is seen that work was scheduled to start on Item A on September 3 but did not start until September 8. The work fell further and further behind until the third floor was completed when it was about a week behind schedule. On this date the progress chart assumed a steeper slope than the time schedule indicating that lost time was being made up. The eighth floor should have been completed October 8 but was completed on October 16, the date of the last report. By projecting the curve, it is

evident that if present progress is maintained the work will be completed on time. Several items may be included on one sheet by using different colors for the lines.

**Cost Charts.** — A simple form of chart showing unit costs for a given class of work is shown in Fig. 167. On the upper part of this figure a

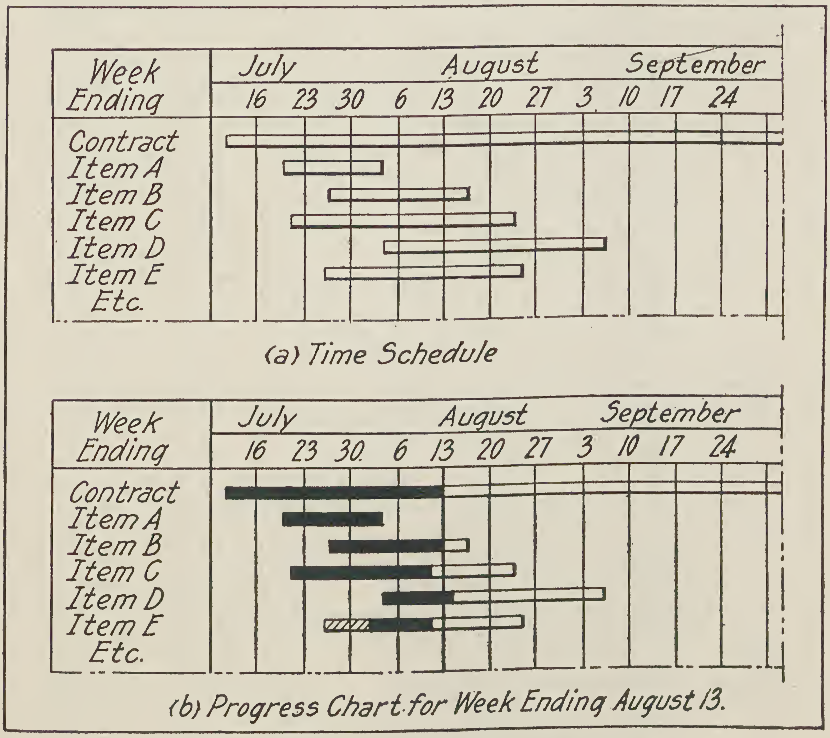


FIG. 165. Time Schedule and Progress Chart

chart for unit costs for the current periods is given. This may show a considerable amount of fluctuation but the lower curve which shows the unit cost to date will fluctuate less for the values given are obtained by dividing the total cost to date by the total quantity to date. These charts show very forcefully how the actual unit costs compare with the estimated values.

Various forms of cost charts are in use showing the cost to date as compared with the estimated cost for the portion of the structure or single item completed to date.

**Progress Photographs.** — On all important construction work photographs should be taken at frequent intervals to show the condition of the

work at the time the picture was taken. These are of value as a matter of record, as a report to the main office, as evidence in the case of law suit and in providing information to assist in the interpretation of cost data. The construction methods used can be illustrated in this way much more clearly than they can be described. It is desirable that one series of pictures be taken from the same spot so as to better to indicate the progress made.

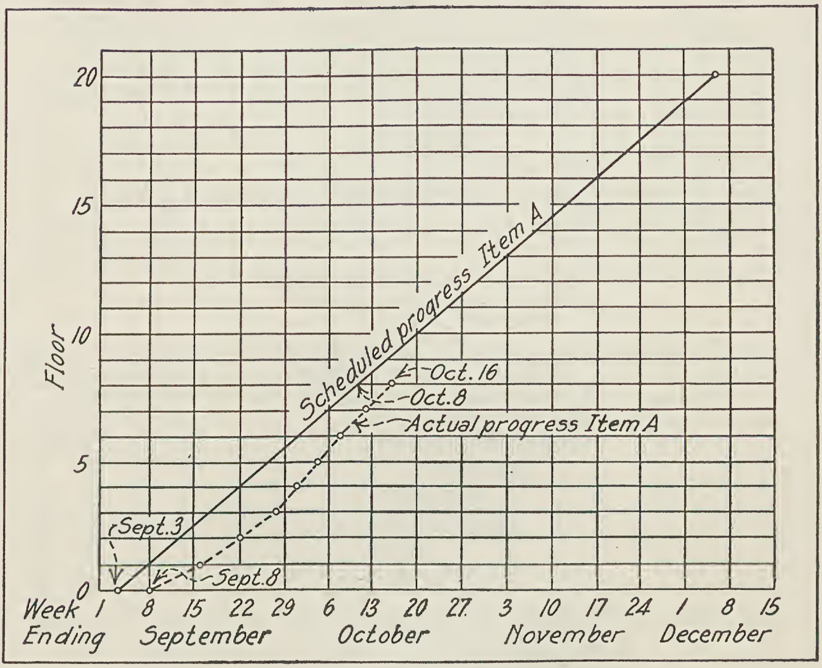


FIG. 166. Time Schedule and Progress Chart

**Job History.** — A history of each job is often required by construction companies. This may be prepared by the superintendent or may be a compilation of the diaries or reports of several men who are connected with the work. It should give the names of those in charge of the work, the prices paid for materials, the wages paid, the methods of construction, a statement of unusual conditions encountered, weather reports, and other pertinent information. In order that such reports may be complete it is often required that they be written out as the work progresses and that copies be sent to the main office at stated intervals.

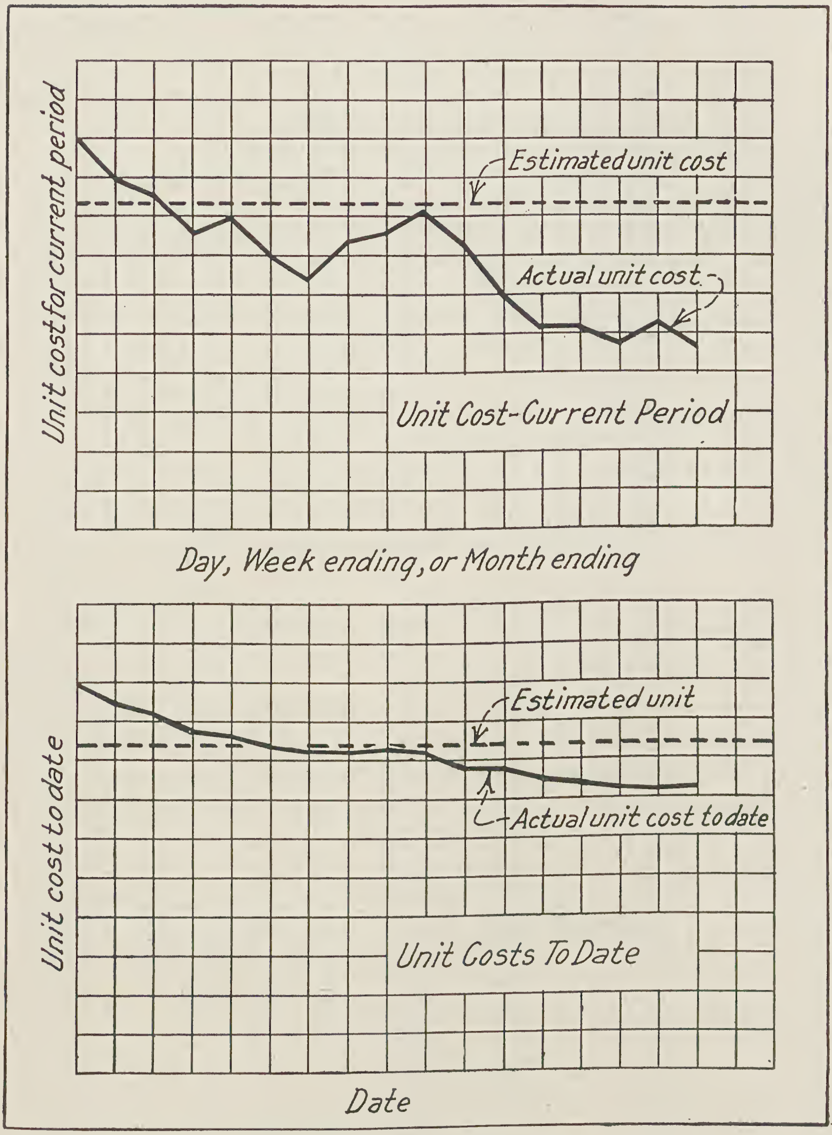


FIG. 167. Charts for Unit Costs

## REFERENCES

Cost keeping systems for various kinds of work are described in the following:

Construction Costs by W. N. Connor. Journal of Boston Society of Civil Engineers, May, 1921.

Highway Cost Keeping by J. J. Tobin and A. R. Losh. Bulletin 660, U. S. Department of Agriculture.

Practical Accounting and Cost Keeping, by Frank R. Walker.

Construction Cost Keeping and Management, by Gillette and Dana.

Practical Accounting for General Contractors by H. D. Grant.

Accounting and Business Methods for Contractors, by C. F. Dingman.

Contractors' Accounting Practice, by W. M. Affelder.

## CHAPTER XVIII

# COST ESTIMATING

### ARTICLE 94. APPROXIMATE ESTIMATES

**Types of Estimates.** — Estimates of the cost of buildings may be divided into two classes: approximate estimates and detailed estimates. Approximate estimates may be sufficiently accurate for the use of architects and engineers in advising their clients of the probable cost of buildings for which working plans are about to be prepared or they may be satisfactory for determining values for the purposes of taxation, insurance, valuation or similar uses. Contractors' estimates for use in submitting lump sum bids must be detailed estimates prepared by making a complete list of all of the material which is to be placed in the building and of all of the work to be done. From this list the cost of the material and of putting it in place is estimated. This list is usually called a *quantity survey.*

**Approximate Estimates.** — Approximate estimates are prepared in many ways, depending upon the data which are available when the estimate is prepared. In the early stages of a building project it may be necessary to form some idea of the probable cost before any work has been done on the plans. Such estimates are bound to be very approximate but may serve the purpose. For instance, some idea of the cost of a building may be determined by knowing the number of rooms and multiplying by the *cost per room* of a similar building. The approximate cost of a hospital may be estimated by multiplying the number of beds to be provided by the *cost per bed* of a similar hospital. The approximate cost of a school building may be determined by multiplying the number of pupils to be accommodated by the *cost per pupil* of a similar school building. In this case wide variations are caused by auditoriums and gymnasiums. Theater, auditorium, and stadium costs are estimated from the number of seats and the *cost per seat;* grain elevator costs, from the capacity and the *cost per bushel of capacity* of similar structures; manufacturing plant costs, from the *cost per unit of daily output;* and electric power plant costs from the *capacity in kilowatts.* All such estimates are of course very approximate but they are quickly prepared with very little information required as to the proposed structure.

**The Square-Foot Method.** — The square-foot method is more accurate than the methods just referred to and is sometimes very useful. Before

the preliminary plans for such a building as a warehouse are prepared, the floor area required may be known. In this case, an approximate estimate of the cost may be determined by *multiplying the number of square feet of floor area required by the cost per square foot of similar buildings.* Outside dimensions, including wall thicknesses, are usually used in computing the floor area. This method is also used when preliminary plans are available, or even the final plans, but in these cases the cubical contents method is preferable.

**Cubical-Contents Method.** — The cubical-contents method is the most satisfactory of all approximate methods for estimating building costs. This method consists of *multiplying the cubical contents or "cubage" of a building by the cost per cubic foot of similar buildings.* At first thought, it would seem that the cubical contents of a building should be a definite quantity upon which all could agree, but this is not the case, the variation between the estimates of different individuals sometimes being as high as 15 or 20 per cent. All agree on using the outside dimensions and the volume of all finished spaces, and nearly all agree on using the volume under the roof. The greatest variation comes in considering the space under the first floor. Some consider the volume included above the basement floor level, some use a level six inches below the basement floor level as a starting point, some use the bottom of the basement floor, and some include the entire volume above the bottom of the footings. If there is no basement floor an element of uncertainty is introduced in the first three methods just mentioned. There is considerable variation in the allowance to be made for open porches, parapet walls, and the projection of chimneys above the roof line. Some estimators include only the finished and usable portion of the building, omitting all unused attic and basement space. This method is a very good one for the use of the owner in comparing the efficiency of several buildings but is not a good guide to construction costs. All agree that unusual construction such as special foundations should be taken care of by adding an appropriate amount to the estimate obtained by using the cubical contents.

As long as one is consistent, and uses the same method in determining the cubical contents of the completed buildings used as an index of cost that he uses in determining the cubical contents of the proposed building, good results can be secured by almost any method; but uncertainty arises when using the cubic foot costs obtained by others who may have followed a different method in determining the cubage.

The American Architect uses the following method in determining the cubical contents of buildings: The extreme dimension of outside walls is used to obtain the ground area. The height is measured from one foot

below the finished basement floor to a point halfway between the level of the wall plates and the ridge of a sloping roof. To this amount is added the cubical contents of enclosed porches and one-half of the cubical contents of open porches and areaways.

The American Institute of Architects has formulated the following standard method for determining the cubage of buildings:[1]

> The cubic content of a building is the actual cubic space enclosed within the outer surfaces of the outside or enclosing walls and contained between the outer surfaces of the roof and six inches below the finished surfaces of the lowest floors.
>
> The above definition requires the cube of dormers, pent houses, vaults, pits, enclosed porches and other enclosed appendages to be included as a part of the cube of the building. It does not include the cube of courts or light shafts, open at the top, or the cube of outside steps, cornices, parapets, or open porches or loggias.
>
> The following items shall be listed separately:
>
> (*a*) Cube of enclosed courts or light shafts open at top, measured from outside face of enclosing walls and from six inches below the finished floor or paving to top of enclosing walls.
>
> (*b*) Cube of open porches measured from outside face of wall, outside face of columns, finished floor and finished roof.
>
> It is recommended that the following items also be listed separately:
>
> (*a*) Square foot area of all stoops, balconies and terraces.
>
> (*b*) Memoranda, or brief description, of caissons, piling, special foundations, or features, if any.

It is quite common to make allowance for the lower cost of open porches by adding only one-fourth or one-half of their volume in determining the total cubage.

Estimates prepared by this method are usually the only ones used by the architect or engineer, the final cost to the owner being determined from the bids submitted by the contractors. If estimates based on the cubical contents are carefully prepared by one who is experienced in the class of building under consideration and who is familiar with local conditions, they should agree very closely with the bids submitted by contractors. Even though such estimates may be satisfactory for the guidance of the owner they should never be used by contractors in submitting bids.

**Typical-Bay Method.** — The cost of buildings which consist of several equal bays may be quite accurately estimated by estimating the cost of one bay and multiplying this cost by the number of bays, making due allowance for end walls, entrances and other features which are not taken care of by the typical bay. This method is more accurate than

[1] A. I. A. Document, No. 239.

the cubic-foot method but is not a suitable method for contractors' estimates.

**Sources of Cost Data.** — The most valuable source of cost data is one's own experience. Most architects and engineers keep a record of the cubic-foot and square-foot costs of the buildings which have been constructed under their direction. Such records should include the total cost of the work, the cubage of the building, the class of construction, the date, a statement of unusual conditions encountered, etc. If the cubic-foot and square-foot costs can be subdivided so as to give the cost of each part of the work, such as excavation, rough carpentry, heating, etc., they will prove valuable in determining the adjustments which should be made to take account of the differences in the type of construction of two structures. For instance, if the cubic-foot cost is so subdivided that the cost of the masonry is shown, the cubic-foot cost of a brick building might be adjusted so that it could be used for a stone building.

Much valuable data on cubic foot costs are given in the construction periodicals such as The American Architect, The Architectural Forum, The Building Age and National Builder, The American Contractor, Engineering News-Record, The Architect and Engineer, The Western Construction News, Engineering and Contracting, The American Builder, and others. Such data may also be secured from The Architect's and Builder's Handbook by Kidder and Nolan, Appraiser's and Adjuster's Handbook by Arthur, School Architecture by Donavan, and Estimating Building Costs by Barnes.

**Cost Indexes.** — The World War brought about a marked increase in building costs which reached a peak in 1920 of nearly three times the pre-war costs and later settled down to a little more than double the costs of 1913. Such changes caused all of the cost data which had accumulated for many years to become valueless until cost indexes showing the changes in building costs during recent years were prepared.

Many such cost indexes are available. That of Engineering News-Record is the most commonly used and is given in Fig. 168 for the years 1903 to 1929. The index number for 1913 is taken as 100 and is based on the prices of steel, cement, lumber, and common labor weighted according to the importance of each in determining construction costs the weight given to each varying from year to year. Although the items on which this index is based are not representative of building construction, the values check remarkably well with building costs. This index appears in the first issue each month of Engineering News-Record.

By the use of index numbers, cost data for any date may be brought up to the present date and used in preparing approximate estimates.

This applies to cubic-foot costs, square-foot costs and other composite costs but not to the cost of one item such as concrete or structural steel which may have had a price trend which is very different from that given by the composite index numbers. Data for the adjustment of individual items are easily secured from construction periodicals.

In bringing old cubic-foot costs up to date by means of cost indexes, due account must be taken of the gradual improvement in the quality of buildings. This improvement is particularly noticeable in plumbing, heating, and mechanical and electrical equipment. Two or more bathrooms are now provided in residences where one would have been con-

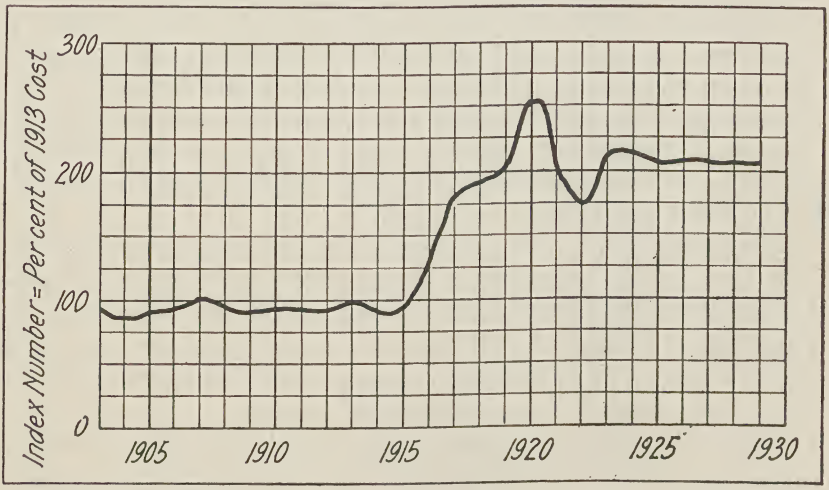


Fig. 168. Cost Index for Buildings

sidered satisfactory a few years ago; tile floors and walls are more extensively used than formerly; plumbing fixtures are of higher quality; oil burners are replacing coal at greater initial cost; steam or hot-water heating systems are being used where hot-air systems were once considered satisfactory; automatic temperature control is becoming more common; conduits are replacing knob and tube systems for electric wiring; more electric outlets are being provided; electric refrigeration is increasing; incinerators are provided; vacuum cleaning systems are being installed; elevator shafts are enclosed where they were formerly left open; elevators are of better design and quality; metal doors, windows, and trim are replacing wood in the higher class of buildings; heat insulation and acoustical treatment are becoming quite common; basement and attic space is being finished; and many other improvements are taking place in addition to the very evident improvement due to the greater use

of fireproof construction which would naturally be taken into account in selecting cubic-foot or square-foot costs. Even if price levels and wages remained constant there would still be a gradual increase in cubic-foot and square-foot costs due to such factors.

**Factors Affecting Cubic-Foot and Square-Foot Costs.** — The cubic-foot cost for a building is determined by many factors, the most important being the prevailing material and labor costs, the type of construction, the materials used, the workmanship required, the mechanical equipment, the conditions under which the work is carried on, the size of the rooms, the story heights, and the size and shape of the building.

Buildings with large rooms will of course cost less per cubic foot and per square foot of floor area than buildings with small rooms. Large story heights will decrease the cubic-foot cost but will increase the square-foot cost. Long narrow buildings will cost more per square foot or cubic foot than square buildings due to the larger amount of exterior wall required. Buildings with large floor areas free from columns will cost more than buildings in which economical column spacings are used. Many other factors might be mentioned.

**Square-Foot Costs.** — The range in floor area costs for buildings with interiors completely finished is from about $4 to $15 or $20 per square foot. The lower figure applies to dwellings, non-fireproof dwellings and apartments with plain finish, and the higher figures to expensively finished fireproof bank buildings, theaters, etc., with high ceilings enclosing large volumes in proportion to the floor area.

Well-constructed non-fireproof dwelling houses will vary in cost from $5 to $8 per square foot of floor area. Well-constructed fireproof office buildings, hotels, hospitals, etc., will vary in cost from $8 to $10 per square foot while the cost of school buildings and apartments of this class will be somewhat cheaper with a lower limit of about $5.

**Cubic-Foot Costs.** — The cubic-foot cost of buildings with interiors completely finished varies from about $0.30 to $1. The lower figure applies to cheaply finished one-story non-fireproof dwelling houses which have relatively large unfinished volumes in the basement and attic while the higher figure may be reached by the highest grade of bank buildings, office buildings or hotels of fireproof construction with elaborate finish and mechanical equipment.

The great majority of buildings such as apartments, dwellings, churches and schools which are well constructed using good materials but where the cost must be kept within reasonable limits range in cost from $0.40 to $0.50 per cubic foot. Theaters, office buildings, club buildings, hospitals, and hotels of this class will range in cost from $0.50 to $0.65 per cubic foot.

Warehouses, garages, factories and similar buildings of non-fireproof construction with light, heat, and a small amount of plumbing but without plaster or interior finish may be constructed for from $0.20 to $0.25 or $0.30 per cubic foot. In some cases the cost has been as low as $0.15 cents per cubic foot for very cheaply constructed buildings of this class.

**Cost per Room.** — The cost of well-constructed non-fireproof dwelling houses without elaborate finish varies from $1500 to $2000 per room whereas the cost of some of the most elaborately finished hotels has been as high as $8000 per room.

**Distribution of Cost.** — In determining the probable effect of changes made in one item upon the total cost of a building it is desirable to know the distribution of the various items of cost which go to make up the total cost and what proportion of the cost of each item is for field labor. Such data are of value also in estimating the approximate cost of items for which figures are not available and in determining the payments which should be made to contractors for partially completed work.

The following figures were compiled from actual costs of buildings which have been constructed and are of value for illustrative purposes in indicating the relative cost of the various parts of buildings. However, considerable variation in such figures must be expected on account of varying designs and specification requirements and differences in material and labor costs and in other factors. The items are arranged in the order of their magnitude.

DISTRIBUTION OF CONSTRUCTION COSTS

Two-Story Frame Dwelling

| | *Per Cent* |
|---|---|
| Carpentry and Millwork | 45.0 |
| Masonry | 11.0 |
| Lathing and Plastering | 10.0 |
| Plumbing | 9.0 |
| Heating | 7.0 |
| Painting | 7.0 |
| Wiring and Fixtures | 4.0 |
| Tile work | 3.0 |
| Sheet Metal | 1.5 |
| Excavation | 1.5 |
| Finish Hardware | 1.0 |
| | 100.0 |

Two-Story Brick Dwelling

| | *Per Cent* |
|---|---|
| Carpentry and Mill Work | 35.0 |
| Brick Masonry | 20.0 |
| Plumbing | 8.0 |
| Steam Heating | 8.0 |
| Lathing and Plastering | 6.0 |
| Painting | 4.0 |
| Tile Work | 4.0 |
| Tile Roof | 4.0 |
| Wiring and Fixtures | 3.5 |
| Walks and Drives | 2.0 |
| Excavation | 1.5 |
| Trim Stone | 1.5 |
| Sheet Metal | 1.5 |
| Finish Hardware | 1.0 |
| | 100.0 |

TWO STEEL-FRAME OFFICE BUILDINGS[1]

| Item | No. 1 | | No. 2 | |
|---|---|---|---|---|
| | Per cent of Total | Field Labor | Per cent of Total | Field Labor |
| General Conditions | 4.3 | 90 | 2.4 | 40 |
| Wrecking and Excavating | 2.6 | 80 | 8.1 | 90 |
| Piling or Caissons | 3.5 | 45 | | 60 |
| Foundations | 3.2 | 45 | [2] | 60 |
| Water and Damp-proofing | .1 | 68 | [3] | 70 |
| Brick Masonry | 6.3 | 40 | 10.7 | 50 |
| Cut Stone and Granite | .1 | 24 | 1.1 | 35 |
| Architectural Terra Cotta | 3.7 | 25 | 2.4 | 26 |
| Reinforced Concrete | 11.4 | 50 | [2] | 50 |
| Tile Fireproofing | 1.4 | 50 | 6.0 | 55 |
| Carpentry | 8.1 | 30 | 9.0 | 40 |
| Lathing and Plastering | 4.0 | 65 | 3.8 | 60 |
| Fireproof Doors and Windows | 1.8 | 20 | 1.3 | 14 |
| Steel Sash | 1.2 | 12 | | 18 |
| Sheet Metal Work | .1 | 24 | .4 | 50 |
| Roofing | .1 | 33 | .2 | 50 |
| Tile, Marble and Terrazzo | 4.2 | 31 | 5.3 | 34 |
| Glazing | .9 | 20 | 1.1 | 15 |
| Painting | .8 | 60 | .9 | 55 |
| Structural Steel | 11.6 | 15 | 14.2 | 23 |
| Ornamental Iron and Bronze | 3.6 | 15 | 4.2 | 14 |
| Hardware | | | .6 | 30 |
| Plumbing | 3.7 | 33 | 4.1 | 34 |
| Heating and Ventilating | 5.7 | 35 | 7.1 | 40 |
| Electric Wiring | 3.1 | 40 | 3.9 | 50 |
| Light Fixtures | | | .4 | 15 |
| Elevators | 5.3 | 20 | 4.0 | 14 |
| Miscellaneous | .2 | 12 | .1 | 50 |
| Vault and Vault Equipment | 3.7 | 20 | | 10 |
| Contractor's Fee | 5.3 | | 8.7 | |
| | 100.0 | 37 | 100.0 | 35 |

[1] Compiled from data issued by S. W. Straus and Co.
[2] In Masonry.
[3] In Roofing.

Cost of Building No. 1, $2,500,000; No. 2, $4,000,000.

Cost of Land for Building No. 2, $1,250,000.

Cost of Financing Building No. 2, $445,000.

Cost of Miscellaneous Carrying Charges, No. 2, $50,000.

The actual building cost for building No. 2 was 67 per cent of the total investment.

The field labor costs given in this table are the ratios in percentages which the cost of the labor at the building bear to the total cost of each item. On building No. 1 the total field labor cost was 37 per cent of the total construction cost; on building No. 2, 35 per cent. In general, the field labor amounts to about 40 per cent of the total construction cost but may be as high as 50 per cent.

## ARTICLE 95. DETAILED ESTIMATES

**Quantity Survey.** — In preparing a detailed estimate of the cost of a given building it is necessary to make a *quantity survey* showing the amount of work of various kinds to be done, such as the number of cubic yards of excavation, the number of cubic yards of concrete in various parts of the work, the number of square feet of concrete forms, the number of pounds of structural steel and reinforcing steel, the number of thousands of brick, and so on through the entire building. Such a survey is prepared from the plans and specifications.

Having determined the quantities of materials, their cost may be found by securing dealers' quotations or by using prices which are known to prevail.

**Labor Constants.** — The labor costs for placing the material are estimated from *labor constants* which are obtained from previous experience or from reference books on estimating. These labor constants are values for the amount of work a man can be expected to do in an hour, such as the number of feet board-measure of timber framing a carpenter can place in an hour, or the number of brick a mason can lay in an hour under specified conditions. The labor of the required helpers should not be overlooked. In this way the hours of labor for the various parts of the work are estimated, and knowing the rate of pay, the labor costs may be estimated. One of the objects of a cost-keeping system is to determine labor constants.

**Unit Costs.** — As a rule, it is convenient to estimate the total material and labor cost of a unit of construction such as a cubic yard of concrete or a thousand face brick. This is called a *unit cost.* The total cost for a given class of work is obtained by multiplying this unit cost by the number of units of work to be done. This method is usually more convenient than estimating the total material cost and the total labor cost for one class of work. Both methods, of course, lead to the same results.

The methods used in estimating the unit costs for the principal classes of work which enter into the construction of a building will be briefly described. The labor constants, wages, and prices used are chosen for illustrative purposes only. In preparing an actual estimate it would be necessary to have the conditions under which the work is to be done more fully stated. Overhead charges, profit, workmen's compensation, liability insurance, and similar items are not included in the examples, only the direct material and labor costs being considered.

For more detailed information see The Building Estimator's Reference Book by Frank R. Walker, to which frequent reference has been made in

preparing this article. Other reference books on estimating are given at the end of this article.

**Overhead Costs.** — The total cost of a building may be divided into two general classes: direct costs and indirect costs. *Direct costs* include the cost of materials and labor which are expended directly on the building and become an integral part thereof. *Indirect costs* include the cost of material and labor which, although necessary in the construction of a building, are not expended directly on the building. The cost of the brick and lumber which become a part of a building are direct material costs and the labor of placing them is a direct labor cost. The cost of the coal used to heat a building during the winter is an indirect material cost and the wage of a watchman is an indirect labor cost.

Indirect costs may be divided into three general classes: office overhead costs, job overhead costs, and plant and equipment costs.

*Office overhead costs* are the indirect costs that are incurred in operating the general office of a contractor or construction company and that cannot be conveniently separated and charged to individual jobs. They include such items as office rent, telephone charges, stenographers' wages, bookkeepers' wages, salaries of executives, cost of office supplies, and advertising costs.

The amount which should be included in an estimate to cover office overhead costs is estimated by using the experience of previous years as a guide. The average annual office expense divided by the average annual volume of business will give a unit cost which may be used to determine an amount which should be added to an estimate in proportion to its magnitude so that the proposed job may bear its share of the contractor's office overhead costs. This operation of distributing certain charges to several accounts or jobs in proportion to their size is called *prorating.*

*Job overhead costs* are the indirect costs which pertain to an individual job. They are often considered as including plant charges but the two will be kept separate in this discussion. Examples of job overhead costs are the salaries of the superintendent, the timekeeper, and the watchman; the cost of power, light, heat, water, and telephone; premiums on fire and liability insurance; snow removal and cleaning rubbish from the building; and the cost of temporary buildings. Job overhead costs should preferably be estimated but usually a percentage, based on past experience, is added to the estimate to cover items which are difficult or impossible to estimate.

**Plant and Equipment Costs.** — Plant and equipment costs are indirect costs due to the concrete mixers, hoists, derricks, trucks, wheel barrows, scaffolding, etc., which are to be used in connection with the work. The most satisfactory method for estimating plant and equipment costs is

probably to consider the equipment on a rental basis even though it is owned by the contractor. The rental charge should include the cost of operation; the average cost of repairs, depreciation, interest on the investment, taxes, and insurance. In estimating the rental charge due account should be taken of the amount of time the equipment is idle during the year. The cost of moving the equipment to and from the job and the cost of installation and dismantling should be included. Considerable experience is necessary before such costs can be accurately estimated.

The Associated General Contractors of America have prepared an equipment rental schedule. The complete schedule may be found in several books, one of which is Estimating Building Costs and Appraising Buildings, by F. E. Barnes. As an illustration of the method of arriving at such costs the basis for determining the annual cost which should be covered by the rental charges, the case of a gasoline concrete mixer, assumed to have a life of four years, will be given.

| | *Per cent* |
|---|---|
| Depreciation considering a salvage value of 25 per cent | 18.75 |
| Interest at $6\frac{1}{2}$ per cent on the depreciated value | 4.00 |
| Shop repairs | 13.00 |
| Field repairs | 8.00 |
| Storage and incidentals | 3.50 |
| Insurance | 1.00 |
| Taxes | 1.00 |
| Total annual expense | 49.25 |

If a piece of equipment is in use only eight months of the year on an average, the monthly rental charge should be one-eighth of the annual expense and not one-twelfth.

**Contingencies.** — Having estimated all of the direct and indirect costs it may be necessary to make some provision for costs which cannot be foreseen but which result from accidents, severe storms, etc., which are not covered by insurance. Such items are called *contingencies.* Contingencies are also considered as including items which have been overlooked in listing the quantities, but by careful estimating such omissions may be avoided. A certain percentage may be added to the cost to cover contingencies.

**Profit.** — An item must also be included for the contractor's profit. This will vary from 5 to 15 or 20 per cent depending upon the size and character of the work and upon the economic conditions which prevail at that time.

**Excavation.** — In estimating the quantity of earth to be removed it is necessary to consider the outside dimensions of the footings and to allow sufficient space for the placing of wall forms, waterproofing, etc. One should determine whether or not the earth banks will stand without being supported and, if not, whether it would be cheaper to excavate the material which caves in or to provide shoring to hold the earth in position. If water is to be encountered the cost of pumping must be included and the additional cost of working under unfavorable conditions should be considered. The kind of earth, the length of haul, and the disposal of the earth all affect the cost. One of the most important items affecting the cost is the kind of equipment which can profitably be used. On a job involving large quantities a steam shovel may be the proper selection, or on small jobs or trenches it may be necessary to use pick and shovel. The cost of clearing the site may have to be included.

To illustrate the method of preparing an estimate for excavation, let it be required to find the cost of excavating a heavy soil by plowing and removing with scrapers. The sources of information concerning labor constants indicate that for the conditions under which this work is to be done a team, driver, and one man holding the plow should loosen about three cubic yards per hour and the same force should remove about two and one-half cubic yards of loosened earth per hour with a scraper. The wages for a man and team will be taken as $1.25 per hour and for a laborer as $0.65 per hour. Overhead costs and profit will not be included. On this basis the cost of plowing one cubic yard is:

| | | |
|---|---|---|
| Team, plow, and driver | $\frac{1}{3}$ hr. @ $1.25 = | $0.42 |
| Extra laborer | $\frac{1}{3}$ hr. @ $0.65 = | 0.22 |
| Total cost of plowing per cubic yard | | $0.64 |

The cost of removing a cubic yard of loosened earth with a scraper is:

| | | |
|---|---|---|
| Team, scraper, and driver | 1 ÷ 2.5 hours @ $1.25 | $0.50 |
| Extra laborer | 1 ÷ 2.5 hours @ $0.65 | 0.26 |
| Total cost of removing with a scraper | | $0.76 |

The total cost per cubic yard for the excavation will therefore be 0.64 + 0.76 = $1.40.

**Concrete.** — The unit used in estimating concrete is the cubic yard. Concrete consists of cement, fine aggregate, and coarse aggregate. The amounts of these materials required for a cubic yard of concrete depend upon the size and grading of the aggregate and upon the proportion of cement required. If arbitrary proportions such as one part cement, two parts fine aggregate and four parts of coarse aggregate are used the

amount of each material required per cubic yard of concrete may be obtained from tables in reference books on concrete or estimating.

The following formula gives fairly accurate quantities for the materials in a cubic yard of concrete when arbitrary proportions are used:

The amount of cement required is:

$$\text{Cement required} = \frac{10.5}{c + s + g} \text{ barrels per cubic yard}$$

where $c$ = number of parts of cement, $s$ = number of parts of fine aggregate, and $g$ = number of parts of coarse aggregate. For 1:2:4 concrete the quantities per cubic yard may be determined as follows:

$$\text{Cement} = \frac{10.5}{1 + 2 + 4} = 1.5 \text{ bbl.}$$

Fine aggregate $= 2 \times 1.5 \times 3.8 \div 27 = .42$ cu. yd.
Coarse aggregate $= 4 \times 1.5 \times 3.8 \div 27 = .84$ cu. yd.
there being 3.8 cu. ft. per barrel and 27 cu. ft. to a cubic yard.

It is quite common among estimators to allow one yard of coarse aggregate and one-half yard of fine aggregate for each yard of concrete. These quantities are somewhat greater than necessary but will make an allowance for waste. In determining the amount of cement required, one sack of cement is considered as a cubic foot and there are four sacks to a barrel. If the Water-cement Ratio Method of proportioning is to be used, the amount of each material required per cubic yard of concrete is determined by experiment with the materials to be used or it may be known from previous experience with the same materials. See Article 6.

Let it be required to find the cost of the materials for a cubic yard of 1:2:4 concrete, the maximum size of the coarse aggregate being one inch. One of the tables which has been referred to gives the quantities required as 1.46 bbl. of cement, 0.44 cu. yd. of fine aggregate, and 0.89 cu. yd. of coarse aggregate. If the cement costs $3.00 per barrel delivered after having taken credit for the sacks returned, fine aggregate, $1.50 per cubic yard, and coarse aggregate, $2.50 per cubic yard, the material cost per cubic yard will be:

| | | | | |
|---|---|---|---|---|
| Cement | 1.46 barrels | @ $3.00 | = | $4.38 |
| Fine aggregate | .44 cu yd. | @ 1.50 | = | .66 |
| Coarse aggregate | .89 cu. yd. | @ 2.50 | = | 2.22 |
| Total material cost per cubic yard | | | | $7.26 |

If materials are not delivered at the site but prices are f.o.b. cars it will be necessary to include the cost of unloading and hauling. A charge for storing the cement may be necessary and the cost of testing the cement may have to be assumed by the contractor. The charge made

for cement furnished in sacks includes a charge of 10 cents each for the sacks. This amount is refunded when the sacks are returned. An allowance should be made for sacks damaged or lost.

The amount of labor required for mixing and placing concrete depends upon the methods used, the distances which the unmixed materials have to be wheeled to the mixer, and the distances the mixed concrete has to be transported. By increasing the plant costs the labor costs may be reduced, so each job must be studied to determine the proper balance between these two items. Except on the smallest jobs concrete is mixed by machine, the size of the mixer depending upon the amount of concrete to be placed and the rate of placing. The materials are usually wheeled to the mixer in wheelbarrows, but belt conveyors are sometimes used. The mixed concrete may be transported in wheelbarrows, in two-wheeled buggies or carts which have two or three times the capacity of wheelbarrows, or it may be hoisted up a tower directly from the mixer and flow down chutes or spouts to any part of the work. The wheelbarrows require only a single plank for a runway but the buggies require a wider and more substantial runway. Wheelbarrows and buggies are raised to the upper floors on a hoist if one is available, or a special hoist may be constructed to hoist the concrete in a skip direct from the mixer and dump it into a hopper on the floor where the concrete is being placed. The wheelbarrows or buggies are filled from the hopper. The plant cost for a spouting system is quite high but the labor cost is low. If the concrete is to be placed in freezing weather, the cost of heating the aggregates and protecting the concrete after it has been placed must be considered.

The factor which sets the pace in depositing concrete is the time required for mixing each batch. On a well organized job it is possible to turn out a batch every two minutes and still allow the materials to remain in the mixer long enough for thorough mixing, but a safer estimate is one batch every two and one-half minutes, allowing for break-downs and other delays.

As an example of the method of arriving at the labor costs for mixing and placing, the case of a job provided with a special concrete hoist will be considered. A mixer of the size known as a one-sack mixer will be used. Such a mixer will hold one sack of cement and the corresponding quantities of aggregate for lean mixtures. For 1:2:4 concrete it will hold one and one-half sacks of cement with the proportionate amounts of fine aggregate and coarse aggregate or $10\frac{1}{2}$ cu. ft. of unmixed material which will yield between 6 and 7 cu. ft. of concrete per batch. If a batch is turned out every $2\frac{1}{2}$ minutes as an average, the capacity per hour will be about 6 cu. yd.

As a basis of arriving at labor costs for mixing, hoisting, and placing, the following organization is used by Walker.[1]

4 laborers wheeling coarse aggregate from stock piles to mixer.
2 laborers wheeling fine aggregate and cement.
1 laborer attending mixer.
1 laborer on floor being poured, attending hopper, and filling barrows.
5 laborers wheeling concrete from hopper to place of deposit.
5 laborers placing screeds, dumping barrows, spreading, grading and tamping concrete, moving runways, etc.
1 laborer for miscellaneous labor, cleaning barrows and mixer, baling cement bags, etc.
1 cement finisher or mason on floor overseeing the work.
1 hoisting engineer.

To place concrete at the rate of 6 cu. yd. per hour with this organization, therefore, requires 19 hours of laborers' time, 1 hour of the finisher's time and 1 hour of the hoisting engineer's time.
The labor cost for 6 cu. yd. would therefore be:

| | | | |
|---|---|---|---|
| Laborers | 19 hrs. | @ $0.65 | $12.35 |
| Cement finisher | 1 hr. | @ 1.25 | 1.25 |
| Hoisting engineer | 1 hr. | @ 1.00 | 1.00 |
| Total labor charge for six cubic yards | | | $14.60 |
| Total labor charge per cubic yard | | | $ 2.43 |

The plant cost for placing concrete varies from one dollar to three dollars per cubic yard, depending upon the size of the job and the kind of equipment used.

**Concrete Forms.** — The most satisfactory method for estimating the cost of wood forms consists of determining the number of feet board-measure required to construct each square foot of forms which comes in contact with the concrete. This, with an allowance for nails, wire, etc., will give the basis for estimating the material cost per square foot of forms.

To determine the labor cost, a figure for the number of feet board-measure which a carpenter with laborers assisting can place in an hour under the prevailing conditions is selected from reference books or by referring to previous experience. Having decided upon the rate at which a carpenter can place the forms a labor cost per square foot of forms can be determined. The sum of material cost and labor cost per square foot of forms will give the total cost per square foot which, when multiplied by the number of square feet of forms in contact with con-

[1] Building Estimators' Reference Book, by Frank R. Walker.

crete, will give the total cost of the forms. Forms of different character should be kept separate, as the amount of lumber per square foot of forms differs for slabs, walls, beams, columns, etc., and the amount of labor required for constructing the various kinds of forms is subject to great variation.

The number of feet board-measure required per square foot of forms in contact with the concrete varies from 2 in the case of light wall forms to 4 or $4\frac{1}{2}$ for forms for heavy floors. Quantities suitable for a given case may be estimated by designing typical forms or by consulting reference books on estimating. It is usually possible to use the form lumber two or three times on each job, thus reducing the cost considerably. In this case it is necessary to make an allowance for tearing the forms to pieces, removing nails, clearing the boards, and waste. The labor cost on used lumber is greater than for new lumber.

To illustrate the method used in estimating the labor cost on concrete forms, let it be required to estimate the labor cost for making and placing forms requiring $2\frac{1}{2}$ ft. board-measure of lumber for each square foot of forms. It is assumed that on forms of the kind under consideration a carpenter will perform the necessary labor on 35 ft. board-measure of lumber per hour and that one-half hour of laborer's time will be required for each hour of carpenter's time. The labor constants for a given case would be determined by consulting reference books on estimating.

On this basis the labor cost for erecting a square foot of forms would be:

| | | |
|---|---|---|
| Carpenter's time.......... | $2.5 \div 35 = 0.071$ hr. @ \$1.25 = | \$0.089 |
| Laborer's time........... | $\frac{1}{2} \times 0.071 = 0.035$ hr. @ .65 = | .023 |
| Total labor cost per sq. ft. of forms.................... | | \$0.112 |

The cost of removing or stripping forms must be added to the cost of erecting. A laborer will remove about 100 ft. board-measure of lumber from forms per hour.

The plant cost including buzz saw, small tools, nails, wire, etc., has been given about one cent per square foot of forms.[1]

**Brick Masonry.**[2] — The unit of measure commonly used in estimating brick masonry is 1000 brick, although the cubic foot of masonry is also used. In determining quantities an effort is made to find the actual number of brick required, considering the size of the brick, the width of the mortar joints, and deducting for all openings. The custom of doubling all corners to make allowance for the greater difficulty of placing

[1] Estimating Concrete Buildings, by C. W. Mayers.

[2] For detailed information see The Building Estimators' Reference Book by Frank R. Walker.

brick at the corners, the allowance of $7\frac{1}{2}$ brick per square foot of wall for each course of brick in thickness regardless of the size of the bricks used, and the figuring of all openings as though they were solid has been largely abandoned.

The cost of brick masonry depends upon whether it is face brick or common, upon the thickness of the wall, the bond used, the type of mortar joint, the kind of mortar, the weather conditions, and many other factors, in addition to the wages of the masons and the cost of brick and other materials used.

The thickness of brick walls is given on plans as 8 in., 12 in., 16 in., etc., or 9 in., 13 in., 17 in., etc., but both designations mean the same, an 8-in. or 9-in. wall being two brick in thickness, a 12-in. or 13-in. wall three brick, and a 16-in. or 17-in. wall four brick. In estimating, it is desirable to use the 8-in., 12-in., 16-in., etc., thicknesses, regardless of the dimensions called for on the plans. The brickwork quantities are then obtained in cubic feet. Unless the actual size of the brick to be used is known, the bricks should be considered as $8 \times 2\frac{1}{4} \times 3\frac{3}{4}$ in., which is the standard size for face brick and common brick. Knowing the size of the brick to be used and the thickness of the mortar joints, the number of brick per cubic foot can be easily calculated. Knowing the number of brick per cubic foot and the number of cubic feet of brickwork, the number of thousand of brick required is easily determined. An addition of about two per cent should be made for waste.

If a wall consists of face brick with common brick backing, the type of bond affects the number of each kind of brick required, because each header projects into the backing, thus increasing the number of face brick required and decreasing the number of common brick a like amount. A 4-in. reveal on the jambs of an opening does not increase the number of face brick after the volume of the opening has been deducted, but greater reveals than this do increase the number of face brick and decrease the number of common brick.

The material cost per thousand brick is determined by adding the cost of brick per thousand including freight and handling charges and the cost of the sand, lime, cement, and mortar color in the mortar. The materials required for the mortar can be determined when it is known that 27 lb. of quicklime or 44 lb. of hydrated lime produce 1 cu. ft. of lime putty and 109 lb. of portland cement produces 1 cu. ft. of cement paste. One cubic foot of lime putty or cement paste and 3 cu. ft. of sand produce 3 cu. ft. of mortar. Other mixtures are in proportion. The amount of mortar color required per thousand brick for each $\frac{1}{8}$ in. of thickness of joint is about 25 lb. for black mortar, 40 lb. for buff or brown, and 50 lb. for red. If metal ties are required their cost must be included.

The brick contractor is often required to furnish ash-pit doors, chimney rods, lintels, anchor bolts, etc., the cost of which should not be overlooked.

The labor cost for making mortar may be determined in two ways. From experience, it is known that one mortar maker can provide sufficient mortar to supply about 8 masons on common brickwork, about 10 masons where face brick is backed up with 8 in. or 12 in. of common brick, and about 20 masons on face brickwork. More detailed figures can be determined by consulting reference books on estimating. Another method of arriving at the labor cost of mortar is to consider that a mortar maker can make about one-half cubic yard of mortar per hour.

The labor cost of laying brick is estimated by determining from reference books or experience the number of brick a mason should lay in an hour on the class of work under consideration and allowing a sufficient amount of laborer's time for carrying brick, mortar, etc., and shifting scaffolding. The number of brick which a mason will lay in an hour varies from 30 to 300, depending upon the character of the work.

For instance, on a 12-in. wall of common brick with lime mortar a mason should lay about 150 brick per hour and about $1\frac{1}{2}$ hour of laborer's time is required for each hour of mason's time.

The labor cost of laying 1000 common brick under these conditions would be about as follows:

| | | | | |
|---|---|---|---|---|
| Mason | 1000 ÷ 150 = 6.67 hr. | @ $1.50 | = | $10.00 |
| Laborer | 10.00 hr. | @ .75 | = | 7.50 |
| Hoisting Engineer | .25 hr. | @ 1.00 | = | .25 |
| Labor cost per 1000 bricks | | | | $17.75 |

These figures include the cost of making the mortar but not the additional wage which a foreman receives.

After face brickwork is completed it must be cleaned with a weak muriatic acid solution. A mason should clean about 600 brick per hour.

**Stone Masonry.** — Stone masonry is divided into three classes depending upon the amount the stones are shaped to fit into position in the wall. In *rubble masonry* the stones are used just as they come from the quarry with no attempt at shaping except possibly by an occasional blow with a hammer. *Squared stone masonry* has stones so shaped that the joints will vary from $\frac{1}{2}$ in. to 1 in. in thickness. *Ashlar* or *cut stone masonry* is made up of stones accurately dressed so that the joints do not exceed $\frac{1}{2}$ in. in thickness.

Rubble masonry is estimated by the cubic foot, the cubic yard, or perch. A perch of stone is ordinarily taken as $16\frac{1}{2}$ ft. (one rod) long by 1 ft. high and $1\frac{1}{2}$ ft. wide and contains $24\frac{3}{4}$ cu. ft. However, a perch is

considered as $16\frac{1}{2}$ cu. ft. in many localities, so it is important that the size of a perch be determined when considering bids on a unit price basis as the usage of any locality will prevail in the case of misunderstanding.

In estimating the material cost on rubble masonry it is necessary to know the volume of wall which can be obtained from a ton, a cubic yard, or a perch of loose stone, the unit of measure used varying with the locality. This will depend upon the characteristics of the stone as some stone is stratified and gives horizontal joints nearly uniform in thickness thus requiring a minimum amount of mortar while other stone is very irregular in shape and requires a large amount of mortar. The amount of mortar will average about one-third of a cubic foot per cubic foot of masonry.

The labor costs on rubble stone are also difficult to estimate without previous experience with the stone to be used. Such costs are estimated by determining as closely as possible the number of cubic feet a mason with laborers assisting, will lay per hour. This will vary from 5 to 15 cu. ft. per hour and will require from 1 to $1\frac{1}{2}$ hours of laborer's time for each hour of mason's time not including the time required for making the mortar.

There is a wide variation in the cost of ashlar or cut stone, the cost depending upon the kind of stone, the kind and thickness of the joints, the surface finish, the size of the stones, the method of bonding, the amount of carving, the character of the moldings, the freight and hauling charges, and many other factors. The unit of measure is the cubic foot, but in the case of steps, sills, copings, belt courses, etc., the lineal foot is sometimes used, or for flagstones and platforms the square foot may be used. In determining the volume of a stone which is not rectangular in shape, the volume of the enclosing rectangle is used.

The amount of mortar required will depend upon the size of the stones, the thickness of the joints, and whether or not back-plastering is required. One cubic foot of mortar will set about 20 cu. ft. of stone not including back-plastering.

The labor cost of setting cut stone will depend upon the size of the stone, the method used in setting, the workmanship required, and many other factors. It is estimated on the basis of the number of cubic feet a mason can set in an hour. This will vary from 8 cu. ft. per hour for small jobs consisting of sills, copings, etc., made up of small stones which can be set by one or two men without the use of derricks, to 30 or 35 cu. ft. per hour on large jobs using power derricks. In the first case it will require about two hours of laborer's time to each hour of setter's time but in the last case quite an organization is required including laborers, derrick-

men, and a hoisting engineer. The cost of setting up the equipment and the rental charges must be included.

After the setting has been completed, the mortar joints must be pointed and the stone work cleaned. A tuck pointer will point from 18 to 35 sq. ft. of stonework per hour depending upon the size of the stones and whether the joints are continuous as in range masonry or broken as in random masonry. Stone can be cleaned at the rate of 50 or 60 sq. ft. per hour.

**Rough Carpentry.** — The following classes of work are included under the head of rough carpentry: Heavy timber framing, including slow-burning construction, roof trusses, etc.; light timber framing, including wood-joist floors, roof rafters, wall and partition studs; wood sheathing for floors, roofs, and side walls; laminated floors; siding, and ceiling; matched floors and parquetry floors; shingle roofs; wood furring and grounds; door bucks, etc.

In general, lumber of all classes is measured in terms of 1000 ft. board-measure, this unit being designated by the letter M. A foot board-measure is one foot square and one inch thick, or its equivalent, containing 144 cu. in. and is designated by the abbreviation b.m. Nominal dimensions are used instead of actual dimensions to allow for sawing the lumber to size and for surfacing. For this reason, and to allow for cutting to lengths an allowance must be made in determining the required quantities. On matched lumber such as flooring, drop siding, and beaded ceilings a considerable addition must be made to make up for the loss of material due to the tongue and groove. In all cases an allowance must be made for the cost of nails. The quantities of nails required for various classes of work are given in reference books on estimating. In estimating quantities one must keep in mind that stock lengths of most lumber run in multiples of two feet.

Timber framing usually is estimated on the basis of the cost per thousand feet board-measure. Figures are available for the number of feet board-measure that a carpenter, assisted by laborers, will frame and place in an hour. For instance, a carpenter will frame and place from 75 to 125 ft.b.m. of wood joists per hour, with one laborer assisting three or four carpenters. On pitched roof construction a carpenter will frame and place from 25 to 45 ft.b.m. per hour, the lower figure applying to roofs involving difficult construction and the larger to straight-forward work. In both cases one laborer should be provided for each three or four carpenters. On roof trusses and heavy timber framing it is desirable to determine the number of operations which must be performed on each piece of timber and estimate the cost of each operation rather than to make an estimate on the basis of the number of board-feet contained in the piece.

Wood sheathing used on floors, roofs, and side walls is estimated on the basis of the cost per thousand feet board-measure. The labor is estimated by determining the number of feet board-measure a carpenter will place in an hour. This varies from 75 ft.b.m. for diagonal sheathing on side walls to 125 ft.b.m. for sub-floors, from $\frac{3}{8}$ to $\frac{5}{8}$ hours of laborer's time being required for each hour of carpenter's time. Since the actual width of sheathing is less than the nominal width and there is some waste in cutting to the lengths required, it is necessary to add from 10 to 15 per cent to the estimated quantities.

Wood flooring may be estimated on the basis of 1000 ft.b.m. of flooring placed or on the basis of 100 sq. ft. of finished floor. Due to the loss in matching, a decided increase must be made in the actual area to determine the quantity of flooring required. For instance, 3-in. flooring has an exposed face of $2\frac{1}{4}$ in. and so requires an addition of $33\frac{1}{3}$ per cent to the area to obtain the quantity of flooring required. The labor required to lay flooring is estimated from the number of feet board-measure or the number of square feet a carpenter can lay in an hour. The labor required in laying 3-in. hardwood flooring may be estimated on the basis of a carpenter laying from 45 to 50 ft.b.m. or 33 to 37 sq. ft. per hour with one laborer to each five carpenters. The labor involved in scraping and sanding floors is estimated on the basis of the number of square feet covered per hour.

Ordinary wood shingles are furnished in bundles which contain the equivalent of 250 shingles 4 in. wide but the shingles are actually of random widths. The unit of measure is usually a square of 100 sq. ft. The number of shingles required per square depends upon how much of the shingle is exposed to the weather. For shingles laid 5 in. to the weather each shingle covers $4 \times 5 = 20$ sq. in. of surface. The number of shingles required to cover 100 sq. ft. or $100 \times 144 = 14{,}400$ sq. in. is $14{,}400 \div 20 = 720$. Adding 10 per cent for waste the number of shingles laid 5 in. to the weather is $720 \times 1.10 = 792$ per square. The labor cost of laying shingles is estimated by determining the number of shingles a shingler can lay per hour. This will vary from 300 to 400, depending upon the character of the work. On the basis of shingles laid 5 in. to the weather and a shingler laying 300 shingles per hour the labor cost per square will be

$$792 \div 300 = 2.64 \text{ hr. @ \$1.25 per hour} = \$3.30.$$

**Finished Carpentry and Millwork.** — The following items are included under finished carpentry: Doors, door frames, door casings, window sash, window frames, window casings, stools and aprons, base, picture

molds, chair and plate rails, wainscoting, wall panels, screens, stairs, mantels, cupboards, etc.

The material necessary for these items is usually furnished by mills which specialize in this class of work. For this reason all of these items are usually classed under the general head of millwork. The ordinary estimator does not attempt to estimate the cost of the millwork but secures his prices from the mill. Built-up fixtures such as mantels, cupboards, etc., are usually furnished ready to install. Door and window frames may be assembled ready to install or may be "knocked down." The simpler moldings, casings, etc., must be cut to length and fitted on the job. A unit used in measuring moldings to determine their cost is the molding inch. It is equivalent to a piece of wood one inch square and one foot long. Prices on moldings are quoted with the molding inch as a unit, prices being given for the various kinds of wood. The cost of stock moldings may be obtained if list prices are available and the prevailing discount is known. In general, the unit of measure for moldings is the lineal foot.

Windows are designated by the glass size, which always gives the width first, the height second, the number of lights third, and the thickness of the sash last, all dimensions being in inches, thus, $24 \times 26$ in., 2 light, $1\frac{3}{8}$ in. The opening size may also be used, in which case the sash thickness is given third and the number of lights last, the dimensions being in feet and inches instead of in inches as when the glass size is used.

Doors are designated by giving the width first, the height second, and the thickness third, all dimensions being in feet and inches. After the dimensions, some symbol may be used to designate the type of door. For instance, 5 c. p. indicates 5 cross panels, 1 Lt. indicates one light of glass, K. D. indicates kalamein door.

Door and window trim, including casings, window stools, and aprons, etc., may be measured by the lineal foot or by the sides of trim, an interior door or window requiring two sides of trim and an exterior door in a masonry wall, one side. The width and height of door or window must be given in listing door and window trim. Jambs require that the wall or partition thickness be given.

The labor cost of installing millwork is often estimated as from 35 to 50 per cent of the cost of the millwork, 40 per cent being the most common value. This method of estimating must necessarily be very inaccurate and should not be used.

The only satisfactory method of estimating the labor cost of installing millwork is to prepare a list of all of the millwork required and estimate the cost of installing each item.

The labor cost of installing such items as wood base, picture mold,

chair rail and the plate rail is estimated by determining the number of lineal feet of such moldings that a carpenter should place in an hour and knowing the total number of lineal feet of each the labor cost is easily estimated. For instance, a carpenter should install about 20 lin. ft. of two-member base an hour, about 30 lin. ft. of picture mold an hour, about 30 lin. ft. of chair rail an hour, and about 12 lin. ft. of plate rail, the actual quantity depending upon the size of the room, the number of breaks, the kind of wood, the class of workmanship, etc.

The labor cost of setting window frames is estimated from the time required to set one frame including the adjusting and bracing. This will depend upon the size of the frame and the kind of wall in which the frame is to be set and will range from 1 to 1½ hours per frame. About one-fourth of an hour of laborer's time is required for each hour of carpenter's time. If the frames are received on the job knocked down they will require about an hour each to put them together.

The labor cost of setting door frames is estimated in the same way as that of window frames, the amount of time required for setting single frames varying from 1 to 1¾ hours and double frames from 2 to 2½ hours.

The labor cost of fitting and hanging window sash is estimated from the time required per sash. This will vary from ½ to ¾ hours each for counterweighted sash or 1 to 1½ hours for the two sash of a double-hung window.

The labor cost of fitting and hanging doors varies with the size of the door, whether it is of softwood or hardwood, and the kind of workmanship required and will vary from ¾ to 2 hours for doors of ordinary size. Mortise locks can be installed in from one-half hour to an hour each.

The interior trim on windows in 12-in. masonry walls including the casings, stool, and apron; and jamb linings requires from 1½ to 2 hours for one-member casings and may require as high as 2½ hours for two-member trim.

The time required to place the trim on one side of a door opening is about ¾ hour for one-member casing and 1 hour for two-member casing.

The total time required to install a window complete including the setting of the frame, fitting the sash, attaching the weights, and placing the trim varies from 4 to 6 hours.

The total time required to install a single door complete including setting the frame, hanging the door, installing the hardware, and placing the trim varies from 4 to 6 hours.

**Lathing and Plastering.**[1] — The unit of measure used for estimating lathing and plastering is the square yard. In general, no deductions are

[1] For detailed information see The Building Estimators' Reference Book by Frank R. Walker.

made for openings but some estimators deduct one-half the size of the openings. Corner beads and moldings are measured by the lineal foot.

The most common size of wood lath is $1\frac{1}{2}$ in. wide by 48 in. long. If a $\frac{3}{8}$-in. space is left between the lath the area covered by one lath is $48 \times 1\frac{7}{8} = 90$ sq. in. The number of lath per square yard would therefore be $9 \times 144 \div 90 = 14.4$. The material cost per 100 sq. yd. of wood lath would be determined as follows:

| | |
|---|---|
| 1440 lath @ $10.00 per M | $14.40 |
| 10 lb. 3d @ .07 per lb | .70 |
| Total per 100 sq. yd. | $15.10 |

The labor cost for placing wood lath may be estimated by assuming that a lather can place about 200 laths per hour or about 14 sq. yd.

On flat surfaces such as walls and ceilings a lather will place from 8 to 12 sq. yd. of metal lath per hour on wood studs or joists.

On this basis the labor cost of placing 100 sq. yd. of $1\frac{1}{2}$-in. $\times$ 4-ft. wood lath would be:

$$100 \div 14 = 7 \text{ hr. @ \$1.50} = \$10.50.$$

Metal lath may be secured in a great variety of patterns and is sold by the square foot or square yard. On plain surfaces an addition of 5 per cent should be made for waste; on more complicated work this allowance should be increased.

The quantities of materials required for plastering depend upon the richness of the mixture, the number of coats required, the thickness, the kind of binder used, and the type of base on which the plaster is applied.

For three-coat work on wood lath with $\frac{3}{4}$-in. grounds using gypsum plaster with white finish, the quantities of materials required for 100 sq. yd. are:

Scratch coat, 1:2 mix, 650 lb. gypsum; 0.50 cu. yd. sand
Brown coat, 1:3 mix, 400 lb. gypsum; 0.45 cu. yd. sand
Finish coat, 285 lb. hydrated lime, 150 lb. plaster of paris.

The material cost per 100 sq. yd. would therefore be:

| | | | |
|---|---|---|---|
| 1050 lb. of gypsum plaster | @ | .80 per hundred | $ 8.40 |
| 150 lb. of plaster of paris | @ | .90 " " | 1.35 |
| 285 lb. of hydrated lime | @ | 1.50 " " | 4.27 |
| .95 cu. yd. of sand | @ | 2.00 per cu. yd. | 1.90 |
| Total material cost per 100 sq. yd. | | | $15.92 |

The labor costs on plastering are estimated by determining the number of square yards a plasterer may be expected to apply in an hour.

This is subject to considerable variation depending upon the quality of the work required. For instance, where good workmanship is required a plasterer should apply about 16 sq. yd. of scratch coat or brown coat per hour or 10 sq. yd. of sand finish or white finish per hour. One hour of laborer's time is required for each hour of plasterer's time.

On this basis the labor cost for 100 sq. yd. of three-coat work with gypsum plaster and white finish would be:

| | | | |
|---|---|---|---|
| Scratch coat | $100 \div 16 =$ | 6.25 hr. | |
| Brown coat | $100 \div 16 =$ | 6.25 hr. | |
| Finish coat | $100 \div 10 =$ | 10.00 hr. | |
| | | 22.50 hr. plasterer's time @ 1.50 = | $33.75 |
| | | 22.50 hr. laborer's time @ .75 = | 16.87 |
| Total labor cost per 100 sq. yd. | | | $50.62 |

Summarizing these items the total cost for 100 sq. yd. of three-coat gypsum plaster with white finish, on wood lath would be:

| | |
|---|---|
| Lath and nails | $ 2.14 |
| Labor on lathing | 10.50 |
| Plaster materials | 15.92 |
| Labor on plastering | 50.62 |
| Total cost per 100 sq. yd. | $79.18 |
| Cost per square yard | $0.79 |

**Painting.** — The units of measure used in estimating painting are the square of 100 sq. ft. or the square yard, and the lineal foot for moldings. The material quantities are determined by the spreading rate of the paint. This is expressed in square feet per gallon of paint and depends upon the nature of the surface to be covered and upon the kind of paint.

There are two general methods for figuring labor costs:

1. For a certain kind of paint placed on a given material the number of square feet of plain surface which is readily accessible a painter will cover in an hour is taken as a constant. The extra labor required by windows and doors, cornices, moldings, balustrades, etc., is taken care of by increasing their areas by factors which take into account the difficulty of the work as compared to work on a plain surface which is readily accessible.

Some examples of the rules used in this method are:

For plain cornices multiply the length by 1½ times the girth. On high buildings where the walls are not to be painted multiply the length by four times the girth.

For plain walls multiply the height by the width and add the areas of the openings.

For plain window sash multiply the height by $1\frac{1}{2}$ times the width.
For fancy sash multiply the height by 3 times the width.
For painted floors use $1\frac{1}{2}$ times the area. For hardwood floors double the area.
For skylights multiply the area by four.

This method gives little idea of the quantity of paint required.

2. In the second method the actual area is determined and the extra labor involved by various classes of work is taken into account by considering that a painter will cover a smaller number of square feet per hour on such work. For instance, in painting porch columns, pilasters, railings, and shutters a painter will cover only about two-thirds the area per hour that he would cover on plain work.

The second method is never followed consistently for all kinds of work for it is universal practice in estimating window openings to figure the area solid with no deduction for the glass area, the additional labor involved in cutting around the edges is being considered as offsetting the labor saved due to the glass area.

Paint may be purchased "ready-mixed" or it may be mixed on the job. The cost of ready-mixed paint may be secured from the dealers but to estimate the cost of paints which are mixed on the job the amount of each ingredient must be known and its cost determined. To illustrate the method of estimating the cost of paint mixed on the job the following example is taken from Walker.[1]

Cost of Cream Paint Mixed on the Job

| | | |
|---|---|---|
| 100 lb. of white lead @ | .14 | $14.00 |
| 2 to 3 lb. of French ocher @ | .14 | .42 |
| $4\frac{3}{4}$ gallons raw linseed oil @ | 1.00 | 4.75 |
| $\frac{1}{2}$ gallon turpentine @ | 1.07 | .54 |
| $\frac{1}{2}$ pint japan drier @ | 2.00 | .13 |
| 2 hr. painter's time @ | 1.25 | 2.50 |
| Total cost of 8 gallons | | $22.34 |
| Average per gallon | | $ 2.79 |

**Structural Steel.** — The units of measure used in estimating structural steel are the ton and the pound. As a rule the information furnished the estimator by the architect's or engineer's plans consists only of the sizes of the main members such as the size of the members of roof trusses, the size of beams, girders, columns and bracing. The details such as the gusset plates of trusses, and the connection of beams and girders, are not shown except that the type of construction desired is shown by typical

[1] Building Estimators' Reference Book, by Frank R. Walker.

details. The quantity of steel required is usually estimated by listing all of the main members, estimating their weight, and adding appropriate percentages for the details. For instance, the details on trusses with members consisting of two angles and single gusset plates will average from 25 to 35 per cent and the details for beams with standard connection will average about 10 per cent. However, if an accurate estimate is desired it is necessary to lay out the details. Having prepared a list of the steel required, the unit costs must next be obtained. They consist of the sum of the following items:

1. Base price of steel plus extras.
2. Freight from mills to structural shop.
3. Cost of assembling and fabricating steel.
4. Cost of shop painting.
5. Freight from shop to building site.
6. Cost of erection including necessary hauling.
7. Cost of painting after erection.
8. Cost of shop drawings.
9. Shop burden or overhead, and profit.

The *base price* of steel is quoted in current engineering periodicals. This base price applies only to certain sizes such as beams and channels 3 in. to 15 in., angles 3 in. to 6 in. on one or both legs by $\frac{1}{4}$ in. thick or thicker. The *extra* on beams larger than 15 in. and angles larger than 6 in. on one or both legs is 10 cents per hundred pounds. For the sizes less than 3 in. the extra is variable and increases in cost per pound as the size decreases. For $\frac{3}{4} \times \frac{3}{4} \times \frac{1}{8}$-in. angles the extra is 35 cents per hundred pounds. There is a *quantity differential* which applies to lots of less than 2000 lb. of one size. This is 15 cents per hundred pounds for lots less than 2000 lb. and 35 cents per hundred pounds for lots less than 1000 lb. There are also extras for cutting lengths less than 3 ft. and for cutting with an accuracy greater than $\frac{3}{8}$-in. overrun or underrun.

A detailed discussion of the other items may be found in reference books on estimating. The estimator usually uses the total cost f. o. b. cars at the shop or the nearest siding to the building site or the total cost erected. He does not attempt to estimate such items as shop costs. Quotations may be on a lump sum or a unit price basis. If quotations are on a unit price basis the method to be used in figuring the weights must be agreed upon. The American Institute of Steel Construction has adopted the following method:

Structural steel and iron sold at a unit price per pound, hundred weight (100 lb.), or ton (2000 lb.) shall be invoiced on the calculated weights of shapes, plates, bars, castings, rivets and bolts, based on the detailed shop drawings and shop bills as follows:

The weight will be figured on the basis of rectangular dimensions for all plates and overall dimensions for all structural shapes, and with no deductions for copes, clips, sheared edges, punchings, borings, milling or planing. When plates can be economically cut in multiples out of one large rectangular plate, then the calculated weight of the plates shall be determined by the area of the large plate.

To the normal theoretical weights of all plates will be added one-half the allowance for overrun in weights in accordance with the specifications of the American Society for Testing Materials.

Another method which is extensively used for bridges makes the *scale weight* the basis of payment for unit price contracts. If this scale weight exceeds the weight computed from the shop drawings by more than $1\frac{1}{2}$ per cent, any further excess will not be paid for. Since it is the object in computing weight under this form of contract to determine as nearly as possible the exact weight, the actual shapes and dimensions of all members are used. All unfilled holes such as those of field rivets are deducted and the weight of the heads only of shop rivets is considered. If material were cut exactly to size and if the sections were accurately rolled to size the computed weight and scale weight would check.

Approximate estimates of the amount of steel required for a building are sometimes required before the designs are prepared. The weight of steel in an office building may be approximated from the amount of steel required per cubic foot of other office buildings. This varies from 2 to 3 lb. The weight of the structural steel required for floors and roofs may be estimated by designing a typical panel or by using data on the weight required per square foot of floor or roof, obtained from other buildings. Many formulas are available for estimating the weight of roof trusses.

**Heating.** — In order to prepare an accurate estimate of the cost of heating systems it is necessary that complete heating plans and specifications be available. These plans and specifications should give the size and type of the boiler and all radiation and the size and quality of all piping. The quality of valves, pipe covering, and all material to be used should be specified. Frequently on small work no plans or specifications are furnished, the only requirement being that the heating system be of sufficient size to heat the building to 70 degrees in the coldest weather. This is of course a very unsatisfactory method to use.

In preparing an estimate for a hot-air system all of the material required should be listed and priced. This includes the furnace, hot-air pipes, cold-air ducts, smoke pipe, registers, etc. The cost of installing is usually estimated as a unit without attempting to divide the costs into individual items.

In estimating the cost of steam and hot-water heating systems a com-

plete list of all of the material required and the corresponding costs should be prepared. This list would include the boiler, radiation, pipe of various sizes, elbows, tees, ells, nipples, valves, pipe covering, smoke pipe, damper, radiator paint, etc. If the heating plans show only the radiation and the boiler size or if time is not available for preparing a detailed estimate the cost of pipe and fittings may be taken as a certain amount per square foot of radiation. Walker[1] gives this as $0.20, with an allowance to be made for the changing price of pipe.

The labor cost for installing a steam or hot-water system may be estimated by estimating the time required to set and connect the boiler and each radiator, by estimating the time required by the piping system making allowances of a certain number of feet of pipe of a given size per hour of steam-fitter's time. The labor of placing the pipe covering is estimated in the same way. The labor required for painting the radiators is estimated by allowing a certain number of square feet of radiation per hour. In all of this work the steam-fitters will be assisted by helpers.

Another method for estimating labor costs on steam and hot-water systems is to allow a certain number of hours of steam fitter's time for each radiator. This allowance includes the labor on the boiler, the piping system and the radiators.

A rapid but approximate method for estimating the total material and labor cost for steam and hot-water systems consists of making an allowance of a certain amount, say $2.00, per square foot of radiation. This amount includes all costs for the complete system installed including the boiler, radiation, pipe and fittings, etc.

**Plumbing.** — In preparing an estimate for plumbing, a complete list is made of all of the fixtures, piping, fitting, valves, etc., required. The cost of each item is determined from dealer's quotations or from catalogue prices reduced in accordance with current discounts. The cost of fittings is frequently estimated by taking their cost as a certain percentage, say 75 per cent,[1] of the cost of the pipe. Under the head of "fittings" are included elbows, tees, crosses and unions. The term "fixtures" includes bath tubs, sinks, bowls, urinals, water closets, laundry trap, shower baths, drinking fountains, water heaters, etc.

The labor required for installing plumbing is estimated from the number of lineal feet of pipe of a given kind and size a plumber and helper may be expected to place per hour, the time required for roughing-in to receive fixtures, and the time required to set each fixture. A more rapid but less accurate method assumes that the labor cost for roughing-in will equal a certain percentage of the cost of the roughing-in materials

[1] Walker's Building Estimator's Reference Book.

and that the labor cost of setting the fixtures will equal a certain percentage of the cost of the fixtures.

The cost of making the connections to the water main and to the sewer should not be overlooked.

Approximate estimates of the cost of plumbing are made by multiplying the number of fixtures by an assumed cost per fixture. This cost per fixture is subject to great variation and depends upon the kind of fixture, its quality, the length of runs, the type of construction of the building, etc., and varies from $75 to $125 installed including all piping, fittings, etc.

**Electric Wiring.** — In order to prepare an accurate estimate of the cost of the material for the electric wiring of a building it is necessary to prepare a detailed list of all of the material required, each item being priced by securing dealer's quotations or from catalogue prices reduced according to current discounts.

The labor costs are estimated from the number of feet of conduit a mechanic can place per hour. The cost of roughing-in ceiling outlets, cabinets, etc., must be included.

A more rapid but less accurate method consists of estimating the cost at a certain sum per outlet. This varies from $3.00 per outlet for knob and tube wiring in frame construction with closely spaced outlets to $10.00 per outlet for conduit work in fireproof buildings. The cost of fixtures must be added as a separate item.

**Unit Costs.** — The Architect and Engineer in each issue gives considerable valuable data concerning building costs in San Francisco. Such data are of interest for comparative purposes. The following data are taken from the October, 1928, issue:

Brickwork —
- Common, $33.00 to $35.00 per thousand laid
- Face, $100.00 per thousand laid
- Brick steps using pressed brick, $1.10 per lin. ft.
- Brick walls using pressed brick on edge, $0.68 per sq. ft.
- Brick veneer on frame buildings, $0.70 per sq. ft.
- Enamel brick, $120.00 per thousand f.o.b. cars
- Common brick, $14.50 plus cartage
- Face, f.o.b. cars, $50.00 per thousand
- Hod carriers, $7.00 per day
- Bricklayers, $11.00 per day

Composition Floors, $0.18 to $0.50 per sq. ft. In large quantities $0.20 per sq. ft. laid

Rubber tile, $0.70 per sq. ft.

Terrazzo floors, $0.60 per sq. ft.

Terrazzo steps, $1.50 per lin. ft.

Mosaic floors, $0.80 per sq. ft.

Damp-proofing —
Two-coat work, $0.20 per yd.
Membrane waterproofing, 4 layers P. B. saturated felt $4.50 per square.
Hot coating work, $2.00 per square.
Wage, roofers, $8.00 per day.

Electric wiring, $3.00 to $9.00 per outlet for conduit work including switches
Knob and tube, $2.25 to $5.00 per outlet including switches
Wage, electricians, $9.00 per day.

Elevators — Prices vary according to capacity, speed and type. Consult elevator companies. Average cost of installing an automatic elevator in 4-story building, $2,600; direct automatic about $2,500.

Fire escapes. Ten-foot balcony with stairs, $65 per balcony.

Glass (not including setting) —

| | |
|---|---|
| Double-strength glass | $0.15 per sq. ft. |
| Quartz glass | $0.50 " " " |
| Plate glass | $0.75 " " " |
| Art glass | $1.00 " " " |
| Wire glass | $0.25 " " " |
| Obscure glass | $0.25 " " " |

Heating. Average $1.70 per sq. ft. of radiation.

Hardwood flooring. Laying and finishing 13/16 $\times$ 2¼ in., $0.16 per sq. ft.; ⅜ $\times$ 2 in., $0.15 per sq. ft.; 5/16 $\times$ 2 in., $0.13 per sq. ft.
Wage, $9.00 per day.

Painting —
Two-coat work, $0.30 per yd.
Three-coat work, $0.40 per yd.
Whitewashing, $0.04 per yd.
Cold water painting, $0.08 per yd.

| Plastering, Interior — | *Per Yard* |
|---|---|
| One-coat, brown mortar only, wood lath | $0.38 |
| Two-coat lime mortar, hard finish, wood lath | .50 |
| Two-coat, hard-wall plaster, wood lath | .53 |
| Three-coat, metal lath and plaster | .95 |
| Keene's cement on metal lath | 1.10 |
| Ceilings, with ¾-in. hot-rolled channels, metal lath only | .67 |
| Ceilings with ¾-in. hot-rolled channels, metal lath plastered | 1.40 |
| Single partition ¾-in. channel, lath one side | .62 |
| Single partition ¾-in. channel, lath two sides, 2 in. thick | 2.20 |
| 4-in. double partition ¾-in. channel, lath two sides | 1.30 |
| 4-in. double partition ¾-in. channel, lath two sides plastered | 2.45 |
| **Plastering, Exterior —** | |
| 2 coats cement finish, brick or concrete wall | 1.00 |
| 2 coats Medusa cement, brick or concrete wall | 1.25 |
| 3 coats cement finish, No. 18 gage wire mesh | 1.75 |

| | |
|---|---|
| 3 coats Medusa finish, No. 18 gage wire mesh | $2.05 |
| Composition stucco | 1.60–2.00 |
| Wood lath, $4.25 per thousand | |
| 2.5-lb. metal lath, dipped | .16 |
| 2.5-lb. metal lath, galvanized | .19 |
| 3.4-lb. metal lath, dipped | .20 |
| 3.4-lb. metal lath, galvanized | .25 |

¾-in. hot-rolled channels, $54 per ton
Hard-wall plaster, $12.95 per ton
Finish plaster, $13.85 per ton
Hydrated lime, $19.50 per ton
Lime, f.o.b. warehouse, $2.25 per barrel
Lime, bulk, $16.00 per ton
Wall board, 5-ply, $43.00 per M
Wages, Plasterer, $11 to $12 per day; lather, $8.50 to $9.00 per day; hod carriers, $7.50 to $8.00 per day

Plumbing. $58.00 per fixture up, according to grade, quantity and runs
Wage, $9.50 per day

Roofing —
Five-ply tar and gravel, $5.25 per square
Tile, $26.00 to $40.00 per square
Redwood shingles, $11.00 per square in place
Cedar shingles, $10.50 per square in place
Wages, Roofers, $8.00

Sheet Metal —
Windows, metal $1.85 per sq. ft.
Fire doors including hardware, $2.15 per sq. ft.

Skylights —
Copper, $1.25 per sq. ft., not glazed
Galvanized iron, $0.30 per sq. ft., not glazed

Stone —
Granite, average, $6.00 per sq. ft. in place
Sandstone, blue, $3.50 per sq. ft. in place
Sandstone, Boise, $2.60 per sq. ft. in place
Indiana limestone, $2.60 per sq. ft. in place
Wage, Stone cutters, $8.50 per day; setters, $9.00 per day.

Steel sash —
All makes from S F. stock, $0.20 to $0.35 per sq. ft. including hardware.

Structural steel —
For average building, $91.00 per ton erected
Light truss work, higher. Plain beam and column work, lower

Tile —

| | | |
|---|---|---|
| White glazed | $0.80 | per sq. ft. laid |
| White floor | .80 | " " " " |
| Colored floor | 1.00 | " " ' " |
| Promenade | .80 | " " " " |
| Wage, tile setter's | 10.00 | per day |

**Sources of Cost Data.** — The following references will be of assistance in preparing detailed cost estimates:

### REFERENCES

Building Estimator's Reference Book, by Frank R. Walker.
Building Labor Calculator, by Gordon Tamblyn.
Estimating Building Costs, by Frank E. Barnes.
Estimating Building Costs, by Charles F. Dingman.
The New Building Estimator's Handbook, by William Arthur.
Estimating and Contracting, by William Radford.
A Complete System for Estimating, Etc., by Alfred J. Donley.
Structural Engineer's Handbook, by M. S. Ketchum.
Estimating Concrete Buildings, by Clinton W. Mayers.
Concrete Costs, by Taylor and Thompson.
Cost Data, by H. P. Gillette.

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